Serum vitamin C and the prevalence of vitamin C deficiency in the United States: 2003–2004 National Health and Nutrition Examination Survey (NHANES)¹,²

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ABSTRACT
Background: Vitamin C (ascorbic acid) may be the most important water-soluble antioxidant in human plasma. In the third National Health and Nutrition Examination Survey (NHANES III, 1988–1994), ~13% of the US population was vitamin C deficient (serum concentrations <11.4 μmol/L).

Objective: The aim was to determine the most current distribution of serum vitamin C concentrations in the United States and the prevalence of deficiency in selected subgroups.

Design: Serum concentrations of total vitamin C were measured in 7277 noninstitutionalized civilians aged ≥6 y during the cross-sectional, nationally representative NHANES 2003–2004. The prevalence of deficiency was compared with results from NHANES III.

Results: The overall age-adjusted mean from the square-root transformed (SM) concentration was 51.4 μmol/L (95% CI: 48.4, 54.6). The highest concentrations were found in children and older persons. Within each race-ethnic group, women had higher concentrations than did men (P < 0.05). Mean concentrations of adult smokers were one-third lower than those of nonsmokers (SM: 35.2 compared with 50.7 μmol/L and 38.6 compared with 58.0 μmol/L in men and women, respectively). The overall prevalence (±SE) of age-adjusted vitamin C deficiency was 7.1 ± 0.9%. Mean vitamin C concentrations increased (P < 0.05) and the prevalence of vitamin C deficiency decreased (P < 0.01) with increasing socioeconomic status. Recent vitamin C supplement use or adequate dietary intake decreased the risk of vitamin C deficiency (P < 0.05).

Conclusions: In NHANES 2003–2004, vitamin C status improved, and the prevalence of vitamin C deficiency was significantly lower than that during NHANES III, but smokers and low-income persons were among those at increased risk of deficiency. Am J Clin Nutr 2009;90:1252–63.

INTRODUCTION

Vitamin C (ascorbic acid) is an indispensable cofactor in the hydroxylation of proline and lysine, and it is essential to collagen synthesis and connective tissue integrity. Vitamin C functions as a reducing agent in hydroxylation reactions catalyzed by dopamine β-monoxygenase and peptidyl glycine α-amidating monoxygenase (1). It plays an important role in increasing the content of endothelial cell tetrahydrobiopterin and thereby increasing the activity of nitric oxide synthase (2). It is involved in the biosynthesis of carnitine, histamine, and several adrenal steroids; it promotes iron absorption and mobilization; and it functions in tyrosine, folate, and xenobiotic metabolism. When intake of vitamin C is below a critical amount (10 mg/d) for prolonged periods, failure of wounds to heal, petechial hemorrhages, follicular hyperkeratosis, bleeding gums, and related abnormalities ensue in a condition known as scurvy (3). Manifest scurvy has rarely been reported in the United States during the past 30 y (4). Latent scurvy characterized by fatigue, irritability, vague, dull aching pains, and weight loss (5) may be underreported because it is not recognized as such.

Although epidemiologic evidence suggests that vitamin C–rich foods play a protective role against development of cancers of the mouth, larynx, esophagus, and stomach (6–8), intervention studies that used supplements have not shown protective effects (9–11). Similarly, epidemiologic studies suggest a lower risk of coronary heart disease associated with higher intakes of fruit, vegetables, and whole grains (12–14); however, prospective studies relating cardiovascular disease with the intake of vitamin C or serum concentrations have provided mixed results (15, 16).

Studies involving food or supplements or both have shown mixed results for the effects of vitamin C on oxidative damage to the eye, hypothesized to be part of the pathogenesis of cataract and macular degeneration. The Age-Related Eye Disease Study (AREDS), a large randomized trial, showed no benefit of 500 mg vitamin C/d (together with vitamin E, β-carotene, and zinc) on the development or progression of cataracts (17). However, two-thirds of the study participants were taking multivitamins containing vitamin C; thus, a treatment effect may have been difficult to discern (18). A 5-y prospective study in Japan that included >700 cases of newly diagnosed cataract found that higher vitamin C intake (dietary and supplemental) was associated with reduced incidence of age-related cataracts (19). Fewer studies have tested the ability of vitamin C to delay or retard the progression of macular degeneration. In the AREDS trial, the antioxidant formulation (vitamins C and E and β-carotene)

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plus zinc delayed progression 5 y after the start of therapy (17); thus, an AREDS-type supplement is currently recommended for persons with certain stages of macular degeneration.

The National Health and Nutrition Examination Survey (NHANES) 2003–2004 is part of the continuous annual survey conducted by the National Center for Health Statistics, Centers for Disease Control and Prevention. It provides important information about the consumption of selected nutrients by providing nutritional biomarker measurements. This report presents the first nationally representative data for serum vitamin C since NHANES III (1988–1994) (20) and compares the prevalence of vitamin C deficiency in the 2 survey periods.

SUBJECTS AND METHODS

Subjects

NHANES 2003–2004 was a complex, multistage, area probability sample that was representative of the US noninstitutionalized civilian population during 2003–2004. Data collection consisted of 3 phases: 1) a screening visit during which sample persons were identified, 2) an interview during which a wide battery of health-related questions were asked, and 3) an examination consisting of direct standardized physical examinations, including body measurements and blood and urine collections, performed in a mobile examination center (MEC). Oversampling was done for elderly individuals, adolescents, pregnant women, Mexican Americans, African Americans, and, beginning in the year 2000, low-income non-Hispanic white persons. Further information on the NHANES survey is available elsewhere (21). The NHANES 2003–2004 sample included 10,791 persons aged ≥6 y, 8378 of whom were interviewed (77.6%) and 7982 of whom were interviewed and examined (74.0%). Approximately 9% (n = 705) of all examined persons had missing data on serum vitamin C. The NHANES 2003–2004 sample included 6916 persons aged ≥20 y, 5041 of whom were interviewed (72.9%) and 4742 of whom were interviewed and examined (68.6%). Approximately 6% (n = 304) of examined adults aged ≥20 y had missing data on serum vitamin C in NHANES 2003–2004.

NHANES III, also a complex, multistage, area probability sample representative of the US noninstitutionalized civilian population, was conducted from 1988 to 1994. The NHANES III sample included 30,930 persons aged ≥6 y, 25,733 of whom were interviewed (83.2%) and 23,070 of whom were interviewed and examined (74.6%) in the MEC. Of these, 11% (n = 2434) had missing serum concentrations of vitamin C. The NHANES III sample included 23,258 persons aged ≥20 y, 18,825 of whom were interviewed (81.0%) and 16,573 of whom were interviewed and examined (71.0%) in the MEC. Of these, 9% (n = 1388) had missing serum concentrations of vitamin C. Details of the NHANES III survey design (22, 23) and vitamin C results for persons 12–74 y of age (20) have been published previously. For most analyses, adults aged ≥20 y, excluding children and adolescents, were considered because younger persons tended to have better vitamin C status than adults.

Design and data collection

Laboratory methods

In NHANES 2003–2004, 7277 persons aged ≥6 y and 4438 adults aged ≥20 y and in NHANES III 20636 persons aged ≥6 y and 15,185 adults aged ≥20 y had total serum concentrations of ascorbic acid (oxidized and reduced) measured. Within 30 min of separation from the clot, one part serum was treated with 4 parts of 6% metaphosphoric acid in the MEC. The stabilized serum samples were stored frozen, then shipped to the Centers for Disease Control and Prevention in Atlanta where they were stored at −70°C until tested. An isocratic reverse-phase HPLC method with electrochemical detection of ascorbic acid was used for NHANES 2003–2004 (24); a similar method was used for NHANES III (25). The analytic method used for NHANES 2003–2004 differed from the one used for NHANES III in 2 important ways. For 2003–2004, but not for NHANES III, calibrators were treated as samples in the assay, ie, subjected to the same sample preparation steps. Similarly, an internal standard was used in all sample preparations to correct results for recovery for NHANES 2003–2004 but not for NHANES III. For both survey periods, 3 levels of bench quality controls, and 2 levels of blind quality controls, were incorporated into each assay. In addition, the laboratory participated in semiannual exercises sponsored by the National Institute of Standards and Technology (NIST; Gaithersburg, MD) for quality assurance for vitamin C analysis (26).

Historical quality assurance data were compared to assess differences in serum vitamin C assay precision with the use of the 2 assay methods. NHANES III bench quality control (QC) data for 3 pools, ranging in concentration from 21.0 to 88.6 μmol/L, had CVs between 5% and 8%. Similarly, during NHANES 2003–2004, 3 bench QC pools, ranging from 13.6 to 122.7 μmol/L, had CVs from 5% to 9%. Blind QC pools (1 in every 20 samples, unknown to analyst, labeled with unique specimen identification numbers) used in NHANES III ranged in concentration from 5.1 to 48.9 μmol/L and had CVs from 51% to 74%. In NHANES 2003–2004, the blind QC pool concentrations ranged from 13.1 to 92.1 μmol/L and had CVs of 5–9%. Split sample data (unknown to the laboratory; n = 151 pairs of split specimens, labeled with different specimen identification numbers) collected during the 6-y course of NHANES III showed an average paired difference CV of 35%. Split sample data were not collected for vitamin C during NHANES 2003–2004. A comparison of the accuracy of methods was made with the use of NIST standard reference materials (2 levels of SRM 970), which were analyzed in 13–14 assays per method over a period of 2 y between survey periods while the new method was being validated. With the use of the NHANES III assay method, values were 92–93% of target values compared with 100–102% of target values with the NHANES 2003–2004 method (24).

With the use of 308 convenience specimens, the average bias between assay methods was 2.6% with the NHANES 2003–2004 method, giving higher values than the NHANES III method (24); however, the bias was concentration dependent with less bias at lower concentrations. For comparison with NHANES 2003–2004, NHANES III data were adjusted with the use of a Deming regression equation, where the adjusted values (y) = 1.0566 (original NHANES III) − 1.9345 μmol/L (24).

Variables

Important correlates of vitamin C concentrations presented in this study include sex, age, race-ethnicity, smoking status, adiposity, socioeconomic status, vitamin C supplement use derived
from a home interview, and dietary intake. Smoking status and adiposity were measured; all other correlates were self-reported.

**Smoking status**

An assessment of tobacco product exposure was based on the measurement of serum cotinine, the primary proximate metabolite of nicotine (27,28). Serum cotinine was measured with the use of a liquid chromatography atmospheric-pressure chemical ionization tandem mass spectrometry procedure (28). Previous studies established that <2% of self-reported tobacco users have serum cotinine concentrations <10–15 ng/mL (27); thus, individuals with concentrations >10 ng/mL cutoff were classified as “smokers” and all others were considered “nonsmokers.” For subjects aged ≥20 y, serum cotinine data from 4434 and 15,053 subjects were available from NHANES 2003–2004 and NHANES III, respectively.

**Body mass index**

Adiposity of adults ≥20 y was assessed with the use of body mass index (BMI; kg/m²). In both surveys, height and weight were measured by trained interviewers with the use of standardized protocols and calibrated equipment. Adults were classified as being obese (BMI ≥30), overweight (BMI of 25–29.9), or healthy weight (BMI of 18.5–24.9) (29). Pregnant females, as determined by a combination of self-report and urinary chorionic gonadotropin, were excluded from the BMI data analysis. Results for underweight adults (BMI <18.5) were not presented because the sample sizes were too small to produce statistically reliable results.

**Socioeconomic status**

Income status was defined with the use of the poverty-income ratio (PIR), which is calculated by dividing family income by a poverty threshold that is specific for family size. This measure of income has the advantage of being relatively stable over time, thus enabling comparisons of PIR groups between NHANES III and NHANES 2003–2004. Low, medium, and high incomes were defined as PIR <1, 1 to <3, and ≥3, respectively. PIR values <1 are below the official poverty threshold, whereas PIR values of ≥1 indicate income at or above the poverty level (30). Of the 4438 adults in NHANES 2003–2004, data from 4195 (94.5%) contained information on PIR; of the 15,185 adults in NHANES III, 13,779 (90.7%) had information on PIR.

**Vitamin C supplement use**

For NHANES 2003–2004 and NHANES III, information pertaining to the use of nutritional supplements was obtained during the home interview for persons aged ≥20 y. In 2003–2004, the question posed was as follows: “Have you taken any vitamins or minerals, or other dietary supplements in the past 30 days? Include prescription and nonprescription supplements.” In NHANES III, during the household interview for persons aged ≥20 y was assessed with the use of body mass index (BMI; kg/m²). In both surveys, height and weight were measured by trained interviewers with the use of standardized protocols and calibrated equipment. Adults were classified as being obese (BMI ≥30), overweight (BMI of 25–29.9), or healthy weight (BMI of 18.5–24.9) (29). Pregnant females, as determined by a combination of self-report and urinary chorionic gonadotropin, were excluded from the BMI data analysis. Results for underweight adults (BMI <18.5) were not presented because the sample sizes were too small to produce statistically reliable results.

**Dietary intake of vitamin C**

Daily intake of vitamin C less than the Estimated Average Requirement (EAR) was calculated for adults ≥20 y based on current recommendations (31) with the use of a single 24-h dietary recall. For women, EAR values are 60 mg/d for nonsmokers and 95 mg/d for smokers; for men, EAR values are 75 mg/d for nonsmokers and 110 mg/d for smokers. Pregnant and lactating women have specifically higher values, namely 70 mg/d for pregnant nonsmokers, 105 mg/d for pregnant smokers, 100 mg/d for lactating nonsmokers, and 135 mg/d for lactating smokers. Estimates of dietary intake of vitamin C were available from 95% and 97% of subjects from NHANES 2003–2004 and NHANES III, respectively.

**Statistical methods**

Because the distribution of serum vitamin C data was highly skewed, a transformation was needed to approximate a Gaussian distribution to construct CIs and to test statistical hypotheses (32,33). The square root transformation optimally improved the data distribution. Estimates of the mean with the use of the square root transformation; 5th, 10th, 25th, 50th (or median), 75th, 90th, and 95th percentiles; and percentage (and SE) of deficient persons (vitamin C <11.4 μmol/L) are presented for persons aged ≥6 y and for persons aged ≥20 y. Sample weights, which account for unequal probability of selection and adjust for nonresponse and noncoverage, were incorporated in estimating means, percentiles, percentages, and their standard errors to obtain unbiased estimates. Standard errors were estimated with the Taylor Series linearization, a design-based approach (32).

CIs were constructed for the mean vitamin C square root transformed and the percentage of persons with vitamin C deficiency. The CIs for mean vitamin C square root transformed were constructed on the square root scale with Wald’s method (34) and then back-transformed. Because the percentage with vitamin C <11.4 μmol/L in most subgroups was relatively small, ranging from 1.0% to 18.0% for NHANES 2003–2004 and from 1.8% to 31.3% for NHANES III, CIs for these percentages were constructed with the arc-sine transformation (32). NHANES III analytic guidelines (23) were used to assess the stability of the percentiles. Minimum sample size needed to present estimated percentiles are a function of the design effect that measures the effect of the complex sample design on the variance estimate and is defined as the ratio of the design-based variance to the variance of a simple random sample of the same size.

Means of vitamin C concentrations (square root transformed) and percentage of persons with vitamin C concentrations <11.4 μmol/L for those aged ≥6 y and those aged ≥20 y were age adjusted by the direct method with the use of the projected US Census population estimates from the year 2000 (35). No discernible bias in serum vitamin C was found because of nonresponse on the basis of age, sex, race-ethnicity, cotinine, BMI, vitamin C supplement use, or dietary intake of vitamin C in either survey period (data not shown).

The data are presented 1) by sex cross-classified by age groups (6–11 y, 12–19 y, 20–39 y, 40–59 y, and ≥60 y) and 2) by sex cross-classified by race-ethnicity (non-Hispanic white, non-
Hispanic black, Mexican American), smoking status (smoker, nonsmoker), and BMI category (healthy weight, overweight, obese), socioeconomic status (low, medium, high), vitamin C supplement use (any, none), and 1-d dietary intake of vitamin C compared with the EAR (less than EAR or greater than or equal to EAR) for both survey periods (1988–1994, 2003–2004). To determine whether stratification was needed in the analysis of mean vitamin C and the percentage of persons with deficient concentrations of vitamin C, we tested for the presence of 2-factor interactions of sex with age group, race-ethnicity, smoking status, BMI, income, vitamin C supplement use, and dietary intake. For NHANES 2003–2004, we showed the existence of interactions between sex and age group for mean serum concentrations of vitamin C ($P < 0.001$) and percentage of persons who were vitamin C deficient ($P < 0.01$). An interaction was also observed between sex and race-ethnicity for mean concentrations of vitamin C ($P = 0.046$). No other 2-factor interactions were significant ($P > 0.05$).

Equality of means or equality of percentages was tested univariately at the $z = 0.05$ level with the Student’s $t$ statistic (33). The equality of $>2$ subgroups was tested simultaneously. If the hypothesis that the means or percentages of all subgroups were equal was rejected, pairwise tests were performed applying the Bonferroni method (36) to control for multiple comparisons. To test for linear and quadratic trends in age and income level, the null hypothesis of no linear or quadratic trend was examined with orthogonal contrast matrices (37). Rejection of this hypothesis implied the existence of a linear or quadratic trend. To investigate the odds ratio for vitamin C deficiency in smokers and nonsmokers during 2 survey periods while controlling for possible confounding variables, a multiple logistic regression analysis was performed. Odds ratios having a 95% CI not including unity were considered significant. We investigated the odds ratios of supplement users and nonusers in a similar manner. The hypothesis that the odds ratio was equal to unity was tested by testing the equivalent hypothesis that the log of the odds ratio was equal to 0.

SAS 9.1 (SAS Institute, Cary, NC) and SUDAAN 10.0 (RTI, Research Triangle Park, NC) were used to construct CIs for the means and percentages, to model odds ratios for vitamin C deficiency among smokers and vitamin C supplement users (SUDAAN, PROC RLOGIST), and to test statistical hypotheses. Unless specified otherwise, data are presented as back-transformed weighted square root transformed mean with 95% CI. Serum vitamin C is indicated in $\mu$mol/L. To convert $\mu$mol/L to mg/dL, multiply $\mu$mol/L by 0.0176.

RESULTS

Age and sex

Marked age-related differences in mean concentrations of vitamin C were evident in the US population and showed a significant quadratic trend in males ($P < 0.001$) and females ($P < 0.001$) (Table 1). Boys 6–11 y of age had the highest mean serum concentrations of any male age group. Similarly, girls 6–11 y of age had the highest mean serum concentrations of any female age group. Both sexes showed a decline in mean concentrations during adolescence ($P < 0.001$). In males, mean values continued to decline from 12–19 to 20–29 y ($P < 0.001$) to a plateau between the ages of 20 and 59 y ($P = 0.546$) and then increased with advancing age ($P < 0.001$). In females, the age pattern was somewhat different. Serum vitamin C decreased linearly from a high point at 6–11 y of age to a low at 20–39 y of age ($P < 0.001$) and then increased to $\geq$60 y of age. Females $\geq$12 y of age had significantly higher mean concentrations of vitamin C than did their male counterparts. Selected percentile data (5th, 10th, 25th, 50th, 75th, 90th, and 95th) for each age group are presented in Table 1.

Race-ethnicity and sex

With the comparison of sexes, women had higher mean concentrations of vitamin C than did men in each of the 3 race-ethnic groups (Table 1). Within sex but stratified by race-ethnic group, no significant differences were observed in mean concentrations of vitamin C among men of different race-ethnicity, but among women of different race-ethnicity, non-Hispanic white women had significantly higher mean concentrations than did non-Hispanic black women. Selected percentile data for each sex stratified by race-ethnicity are shown in Table 1.

Smoking

The mean serum concentration of vitamin C of all smokers was 33% lower than that of all nonsmokers (data not shown). Men who smoked had mean serum concentrations of vitamin C that were 31% lower than nonsmoking men, whereas women smokers had concentrations that were 33% lower than nonsmoking women (Table 2). Selected percentile data for each smoking status group stratified by sex are shown in Table 2.

Body mass index

Mean serum vitamin C was significantly lower in obese men than in overweight men (15% lower) but not significantly different between overweight and healthy-weight men (Table 2). For women, mean vitamin C was significantly lower in obese than in overweight (15% lower) or healthy-weight (25% lower) women. Selected percentile data for each BMI category are shown in Table 2.

Socioeconomic status

In men and in women, mean vitamin C increased linearly with increasing PIR (Table 2). In men, vitamin C concentrations were significantly higher in high compared with low PIR groups (33% higher). In women, vitamin C concentrations were significantly higher in medium compared with low PIR (20% higher), high compared with medium PIR (14% higher), and high compared with low PIR (37% higher) groups. Selected percentile data for each PIR category are shown in Table 2.

Vitamin C supplement use

Mean serum concentrations of vitamin C in different age groups in vitamin C supplement users and nonusers are shown in Figure 1. The quadratic age trends in mean concentrations of vitamin C seen in all males and females were retained when the data were stratified by supplement usage ($P$ for trend $< 0.001$). Among nonusers, boys had significantly higher means than did girls ($P < 0.01$); however, in age groups $\geq 12$ y, female nonusers
TABLE 1
Serum vitamin C concentrations (in μmol/L) of persons in different age or race-ethnic groups, stratified by sex in the United States, 2003–2004

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean (^1)</th>
<th>Lower</th>
<th>Upper</th>
<th>5th</th>
<th>10th</th>
<th>25th</th>
<th>50th</th>
<th>75th</th>
<th>90th</th>
<th>95th</th>
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</thead>
<tbody>
<tr>
<td>Age adjusted(^4)</td>
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<tr>
<td>≥6 y</td>
<td>7277</td>
<td>51.4(^6)</td>
<td>48.4</td>
<td>54.6</td>
<td>8.5</td>
<td>14.7</td>
<td>34.5</td>
<td>56.3</td>
<td>72.8</td>
<td>90.7</td>
<td>103.5</td>
</tr>
<tr>
<td>≥20 y</td>
<td>4438</td>
<td>49.0(^7)</td>
<td>45.8</td>
<td>52.3</td>
<td>7.6</td>
<td>13.1</td>
<td>31.7</td>
<td>54.4</td>
<td>70.7</td>
<td>88.9</td>
<td>102.1</td>
</tr>
<tr>
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<td>44.9</td>
<td>51.2</td>
<td>7.3</td>
<td>13.1</td>
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<td>52.7</td>
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<td>85.5</td>
<td>100.4</td>
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<td>2153</td>
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<td>41.3</td>
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<td>6.6</td>
<td>10.7</td>
<td>27.1</td>
<td>50.1</td>
<td>65.5</td>
<td>80.3</td>
<td>98.2</td>
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<td>6–11 y</td>
<td>400</td>
<td>73.5</td>
<td>69.8</td>
<td>77.3</td>
<td>—</td>
<td>43.6</td>
<td>59.8</td>
<td>76.7</td>
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<td>108.0</td>
<td>—</td>
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<td>12–19 y</td>
<td>1037</td>
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<td>47.2</td>
<td>54.2</td>
<td>13.6</td>
<td>20.6</td>
<td>36.8</td>
<td>54.3</td>
<td>67.9</td>
<td>85.1</td>
<td>92.4</td>
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<td>37.6</td>
<td>46.6</td>
<td>6.7</td>
<td>10.3</td>
<td>26.0</td>
<td>46.6</td>
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<td>40–59 y</td>
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<td>47.6</td>
<td>6.2</td>
<td>9.5</td>
<td>25.5</td>
<td>48.7</td>
<td>64.0</td>
<td>79.6</td>
<td>98.1</td>
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<tr>
<td>≥60 y</td>
<td>800</td>
<td>52.5(^7)</td>
<td>48.8</td>
<td>56.4</td>
<td>8.1</td>
<td>15.0</td>
<td>35.6</td>
<td>57.7</td>
<td>74.3</td>
<td>97.6</td>
<td>113.5</td>
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<tr>
<td>≥6 y</td>
<td>3687</td>
<td>54.8(^6)</td>
<td>51.6</td>
<td>58.0</td>
<td>9.8</td>
<td>16.7</td>
<td>38.7</td>
<td>59.8</td>
<td>76.9</td>
<td>94.8</td>
<td>107.6</td>
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<td>≥20 y</td>
<td>2285</td>
<td>53.1(^3)</td>
<td>49.9</td>
<td>56.5</td>
<td>9.2</td>
<td>15.1</td>
<td>37.5</td>
<td>58.9</td>
<td>75.8</td>
<td>93.1</td>
<td>107.0</td>
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<tr>
<td>6–11 y</td>
<td>423</td>
<td>68.9</td>
<td>64.7</td>
<td>73.3</td>
<td>—</td>
<td>36.4</td>
<td>55.5</td>
<td>70.0</td>
<td>87.2</td>
<td>106.9</td>
<td>—</td>
</tr>
<tr>
<td>12–19 y</td>
<td>979</td>
<td>54.8(^8)</td>
<td>50.6</td>
<td>59.2</td>
<td>13.5</td>
<td>19.0</td>
<td>38.2</td>
<td>59.2</td>
<td>75.9</td>
<td>91.6</td>
<td>102.3</td>
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<tr>
<td>20–39 y</td>
<td>815</td>
<td>48.8(^8)</td>
<td>44.5</td>
<td>53.3</td>
<td>8.4</td>
<td>13.3</td>
<td>33.0</td>
<td>54.1</td>
<td>71.7</td>
<td>87.4</td>
<td>97.7</td>
</tr>
<tr>
<td>40–59 y</td>
<td>638</td>
<td>52.0(^8)</td>
<td>47.5</td>
<td>56.7</td>
<td>7.9</td>
<td>15.0</td>
<td>36.3</td>
<td>57.8</td>
<td>73.1</td>
<td>89.8</td>
<td>102.6</td>
</tr>
<tr>
<td>≥60 y</td>
<td>832</td>
<td>62.9(^8)</td>
<td>60.5</td>
<td>65.4</td>
<td>13.1</td>
<td>21.8</td>
<td>47.7</td>
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<td>86.1</td>
<td>106.7</td>
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<td>Adults age ≥20 y by race-ethnicity(^9)</td>
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<tr>
<td>Mexican American</td>
<td>433</td>
<td>44.3(^5)</td>
<td>39.5</td>
<td>49.4</td>
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<td>18.0</td>
<td>36.4</td>
<td>51.6</td>
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<tr>
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<td>49.0</td>
<td>6.4</td>
<td>9.5</td>
<td>25.7</td>
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<td>42.4(^5)</td>
<td>38.5</td>
<td>46.5</td>
<td>6.8</td>
<td>12.8</td>
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<td>46.4</td>
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<tr>
<td>Mexican American</td>
<td>459</td>
<td>51.2(^6,10)</td>
<td>45.7</td>
<td>57.0</td>
<td>—</td>
<td>22.7</td>
<td>39.7</td>
<td>54.6</td>
<td>70.0</td>
<td>82.6</td>
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<td>Non-Hispanic white</td>
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<td>49.7</td>
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<td>8.5</td>
<td>14.1</td>
<td>38.5</td>
<td>61.0</td>
<td>78.6</td>
<td>96.6</td>
<td>112.1</td>
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<tr>
<td>Non-Hispanic black</td>
<td>441</td>
<td>46.3(^5,11)</td>
<td>43.4</td>
<td>49.4</td>
<td>10.6</td>
<td>16.1</td>
<td>31.3</td>
<td>49.0</td>
<td>65.2</td>
<td>80.7</td>
<td>89.8</td>
</tr>
</tbody>
</table>

\(^1\) Weighted square root transformed; equality of means tested on a square root scale with Student’s t statistic with 15 df.
\(^2\) Calculated on the basis of raw data (weighted untransformed data).
\(^3\) Includes all race-ethnic categories.
\(^4\) Age-adjusted by using the direct method to the year 2000 US census population estimates with the use of age groups 6–11, 12–19, 20–39, 40–59, and ≥60 y (35).
\(^5\) Adjusted by using the direct method to the year 2000 US census population estimates with the use of age groups 20–39, 49–59, and ≥60 y (35).
\(^6\) Percentiles do not meet standards for reliability because of small cell size (23).
\(^7\) Significantly different from 6–11-y-old boys, P < 0.001.
\(^8\) Significantly different from 6–11-y-old girls, P < 0.001, and males in respective age groups, P < 0.005.
\(^9\) Race and ethnicity were self-reported.
\(^10\) Significantly different from men in respective race-ethnic group, P < 0.001.
\(^11\) Significantly different from non-Hispanic black men, P < 0.05, and non-Hispanic white women, P < 0.001.

had significantly higher mean concentrations than did male nonusers (Figure 1). Among users, women aged ≥60 y had significantly higher means than did men aged ≥60 y older (P < 0.001). In those adults aged ≥20 y for whom serum vitamin C measurements were available, 37% of men and 47% of women reported consuming one or more vitamin C–containing supplement in the past 30 d (Table 3). Vitamin C supplement users had significantly higher mean serum concentrations of vitamin C than did nonusers of vitamin C supplements. Selected percentiles of serum concentrations of vitamin C are presented by sex and use of vitamin C supplements in Table 3.

**Dietary intake of vitamin C**

Among adults aged ≥20 y who had serum measurements of vitamin C available, 60% of adult men and 53% of adult women reported dietary intake of vitamin C less than the EAR. Men and women with vitamin C intakes greater than or equal to the EAR on the day before examination had significantly higher mean concentrations of vitamin C than did their counterparts whose vitamin C intake was less than the EAR (Table 3). Within each vitamin C dietary intake group, mean serum vitamin C concentrations of women were higher than those of men.

**Vitamin C deficiency in NHANES 2003–2004**

A serum concentration <11.4 μmol/L is considered to be indicative of vitamin C deficiency at which time clinical features of manifest scurvy may be seen (38). Of the total population in NHANES 2003–2004, 7.1 ± 0.9% (±SE) were deficient (Table 4). Only a small percentage of 6–11-y-old participants (<2%) and relatively few adolescents (<4%) were deficient. A
TABLE 2
Serum vitamin C concentrations (in μmol/L) of adults ≥20 y of all race-ethnic categories in different smoking, BMI, or socioeconomic status categories, stratified by sex in the United States, 2003–2004

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean</th>
<th>Lower</th>
<th>Upper</th>
<th>5th</th>
<th>10th</th>
<th>25th</th>
<th>50th</th>
<th>75th</th>
<th>90th</th>
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<tr>
<td>Nonsmokers</td>
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<td>50.7</td>
<td>47.2</td>
<td>54.3</td>
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<td>18.3</td>
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<td>68.7</td>
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<td>41.8</td>
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<tr>
<td>Healthy weight</td>
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<td>46.0</td>
<td>40.5</td>
<td>51.7</td>
<td>6.7</td>
<td>10.4</td>
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<td>52.8</td>
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<td>43.3</td>
<td>50.9</td>
<td>7.5</td>
<td>13.7</td>
<td>30.7</td>
<td>53.6</td>
<td>66.5</td>
<td>81.4</td>
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<td>115.5</td>
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<td>49.2</td>
<td>56.6</td>
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<td>20.4</td>
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<td>59.5</td>
<td>76.1</td>
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<td>45.5</td>
<td>6.4</td>
<td>10.2</td>
<td>24.0</td>
<td>47.4</td>
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<td>87.7</td>
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<td>13.5</td>
<td>31.7</td>
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<td>101.6</td>
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<td>21.9</td>
<td>44.3</td>
<td>62.9</td>
<td>78.6</td>
<td>96.1</td>
<td>114.7</td>
</tr>
</tbody>
</table>

1. Weighted square root transformed; age-adjusted with the direct method to the year 2000 US census population with the use of the age groups 20–39, 40–49, and ≥60 y (35); equality of means tested on a square root scale with Student’s t statistic with 15 df.
2. Calculated on the basis of raw data (weighted untransformed data).
3. Smoker is defined as having serum cotinine ≥10 ng/mL; nonsmoker has cotinine ≤10 ng/mL.
4. Means increased linearly with increasing PIR,
5. Rounded to the nearest 10th; pregnant women and adults with BMI (in kg/m²) <18.5 were excluded. BMI categories are defined as 18.5 to <25 (healthy weight), 25 to <30 (overweight), and ≥30 (obese).
6. /10 Significantly different from healthy-weight women: /10 p < 0.001, /10 p < 0.0001.
7. Significantly different from overweight men, P < 0.01.
8. Significantly different from obese women, P < 0.001.
9. Defined as poverty-income ratio (PIR) of <1 (low), 1 to <3 (medium), or ≥3 (high).
10. Means increased linearly with increasing PIR, P < 0.05 (Student’s t statistic with 15 df).
11. Percentiles do not meet standards for reliability because of small cell size (23).
12. Significantly different from men with low PIR, P < 0.01.
13. Significantly different from women with high PIR and with low PIR, P < 0.05.
14. Significantly different from women with low PIR, P < 0.05.

The percentage of adults with deficient concentrations of vitamin C in NHANES 2003–2004 was markedly higher among smokers than among nonsmokers (Table 5). Smokers were at risk of deficiency >3 times as often as nonsmokers. In adults, BMI was not related to the prevalence of vitamin C deficiency (Table 5). The percentage of men and women with vitamin C deficiency decreased linearly with increasing PIR (Table 5). The prevalence of vitamin C deficiency was higher in low-income (17.4%) compared with the high-income (7.9%) men and in low-income (10.4%) compared with high-income (5.0%) women.

Adults who were nonusers of vitamin C supplements had a significantly higher prevalence of vitamin C deficiency than did users (Table 6). The prevalence of vitamin C deficiency among nonusers of vitamin C supplements was higher in men and in women. Adults with vitamin C intake less than the EAR had a significantly higher prevalence of vitamin C deficiency than did adults with vitamin C intake greater than or equal to the
In both surveys, smokers had a higher prevalence of vitamin C deficiency than did nonsmokers (Table 5). However, in NHANES 2003–2004 the prevalence of vitamin C deficiency among all smokers declined significantly compared with NHANES III (41–42% decrease); nonsmokers showed a similar improvement (42–44% decrease). The significant association of smoking status and vitamin C deficiency persisted after controlling for the possible confounding effects of sex, age, race-ethnicity, BMI, income, use of vitamin C–containing supplements, dietary intake of vitamin C, and survey (odds ratio: 3.76; 95% CI: 3.08, 4.59; P < 0.001). Despite a decline, smokers remained the subgroup most at risk of vitamin C deficiency (Table 5). Significant declines in the prevalence of vitamin C deficiency in 2003–2004 were observed in most BMI-related categories except for obese men who had the smallest improvement in vitamin C deficiency (22% decrease) of any subgroup (Table 5). In low and medium income but not high income groups, the prevalence of vitamin C deficiency declined between surveys in all 3 income groups (34–49%; Table 5).

Comparing the prevalence of vitamin C deficiency in the 2 surveys by vitamin C supplement use, an improvement was observed within each of the 4 sex-by-vitamin C supplement use groups (Table 6). The low prevalence of deficiency in vitamin C supplement users in NHANES III was further reduced by 60–62% in NHANES 2003–2004. The significant association of vitamin C supplement use and low risk of vitamin C deficiency persisted after controlling for the possible confounding effects of sex, age, race-ethnicity, BMI, PIR, smoking status, dietary intake of vitamin C, and survey (odds ratio: 5.21; 95% CI: 3.98, 6.83; P < 0.001). In both categories of dietary intake, vitamin C status improved in NHANES 2003–2004 compared with NHANES III (Table 6). Women whose dietary intake of vitamin C was greater than or equal to the EAR were the least likely of any subgroup to be vitamin C deficient and showed the greatest improvement in status since NHANES III (80% decrease in deficiency).

**DISCUSSION**

Data on serum vitamin C from the nationally representative NHANES 2003–2004 survey show that the vitamin C status improved in the US population since 1988–1994. In virtually all subgroups explored in this analysis, fewer persons were categorized as deficient, and most differences were significant. The race-ethnic differences in the prevalence of vitamin C deficiency seen in NHANES III were no longer apparent in the 2003–2004 survey period. The magnitude of the improvement (56–73%) was striking for minority groups. Although non-Hispanic black women had significantly lower mean concentrations than did non-Hispanic white women in NHANES 2003–2004, the prevalence of deficiency was not lower, a suggestion that there are different distributions of values in the 2 groups of women. Each of the 3 race-ethnic groups showed a significant sex difference in serum concentrations of vitamin C in NHANES 2003–2004. Higher concentrations in females have been observed in other studies in the United States (20, 42) and Europe (43–45), although not noted in an Asian population (46). The inverse relation between BMI and serum concentrations of vitamin C seen in NHANES 2003–2004 had been noted previously (45, 47). Lower vitamin C intake and more prevalent vitamin C deficiency among persons with low income status have been reported in other populations (48–50).
Vitamin C dietary intake
8
Vitamin C supplement use
4
the same period (56). Increased intake of vitamin C–containing consumption declined slightly from 3.4 to 3.2 servings/d during 1994–1996 to 1999–2002 (1.6 servings), and average vegetable by sex in the United States, 2003–2004
Group

Mean
95% Confidence
Percentile
confidence

limits

n

Lower
Upper
5th
10th
25th
50th
75th
90th
95th

Vitamin C supplement use

Men

Users
788
60.6
58.1
63.1
19.7
32.9
48.7
61.7
76.2
98.2
111.4

Nonusers
1360
35.1
31.4
39.1
5.2
7.9
18.6
38.5
57.1
68.6
75.9

Women

Users
1,070
66.3
63.3
69.4
26.0
37.9
54.5
67.7
84.6
102.7
120.4

Nonusers
1,211
42.2
38.5
46.0
6.9
10.0
23.7
46.6
65.2
83.4
92.7

Vitamin C dietary intake

Men

Greater than or equal to the EAR
816
58.6
53.9
63.4
—
—
—
—
—
—
—

Less than the EAR
1227
37.6
33.9
41.4
—
—
—
—
—
—
—

Women

Greater than or equal to the EAR
1011
64.3
61.1
67.6
—
—
—
—
—
—
—

Less than the EAR
1159
46.1
42.3
50.1
—
—
—
—
—
—
—

† EAR, Estimated Average Requirement.
† Weighted square root transformed; age-adjusted with the direct method to the year 2000 US census population with the use of the age groups 20–39, 40–59, and ≥ 60 y (35); equality of means tested on a square root scale with Student’s t statistic with 15 df.
†† Calculated on the basis of raw data (weighted untransformed data); data not shown for categories based on 1-d estimate of dietary intake because of overestimation of probabilities in tails (31).
* Defined as having taken one or more vitamin C–containing supplement during the previous 30 d.
† Significantly different from men who were nonusers and women who were users, P < 0.001 (Student’s t statistic with 15 df).
† Significantly different from women who were nonusers, P < 0.001 (Student’s t statistic with 15 df).
††† Significantly different from men who were nonusers, P < 0.001 (Student’s t statistic with 15 df).
*† Based on a single 24-h recall interview; EAR is defined as the daily intake that is estimated to meet the requirement in one-half of apparently healthy persons in a life-stage or sex group (31).
* Significantly different from men with intake less than the EAR and women with intake greater than or equal to the EAR, P < 0.001 (Student’s t statistic with 15 df).
††† Significantly different from men with intake less than the EAR and women with intake greater than or equal to the EAR, P < 0.001 (Student’s t statistic with 15 df).
†† Significantly different from women who were nonusers, P < 0.001 (Student’s t statistic with 15 df).
† Significantly different from women who were nonusers, P < 0.001 (Student’s t statistic with 15 df).
†† Significantly different from men who were nonusers and women who were users, P < 0.001 (Student’s t statistic with 15 df).
†† Significantly different from men who were nonusers and women who were users, P < 0.001 (Student’s t statistic with 15 df).
† Significantly different from men who were nonusers, P < 0.001 (Student’s t statistic with 15 df).
†† Significantly different from men who were nonusers, P < 0.001 (Student’s t statistic with 15 df).
† Significantly different from men who were nonusers, P < 0.001 (Student’s t statistic with 15 df).
†† Significantly different from men who were nonusers, P < 0.001 (Student’s t statistic with 15 df).

On the basis of NHANES serum cotinine data, the prevalence of adult smoking decreased from 25.5 to 22.7% between 1990 and 1999 (51). Serum cotinine concentrations in nonsmokers decreased by ≈ 70% between 1988 and 2002 (52). Among smokers, there has been a decrease in cigarette use. From NHANES III to NHANES 1999–2000, the average number of cigarettes smoked per day fell by 15%, and mean serum cotinine fell in smokers by 13% (53). Since NHANES III, many communities have banned smoking in public places and consequently reduced passive exposure to secondhand smoke (52). Thus, it seems likely that a reduction in smoke exposure in smokers and nonsmokers alike may account in part for the improvement in vitamin C concentrations in the population during 2003–2004.

The relation between serum concentration of vitamin C and age in the US population is complex and nonlinear. This relation appears to be different from country to country, depending on such factors as the availability of fruit and vegetables, socioeconomic levels, and supplement usage (48, 54). Fruit and vegetable consumption among American adults remained relatively stable from 1994 through 2005 (55). For example, average daily fruit intake in persons ≥ 2 y of age remained the same from 1994–1996 to 1999–2002 (1.6 servings), and average vegetable consumption declined slightly from 3.4 to 3.2 servings/d during the same period (56). Increased intake of vitamin C–containing foods was unlikely to have contributed to the reduced prevalence of vitamin C deficiency during the recent survey. Mean 1-d intakes of vitamin C from food in those aged ≥ 12 y ranged from 91 to 125 mg during NHANES III (20), whereas in NHANES 2003–2004, mean 1-d intakes were slightly lower, ranging from 80 to 116 mg (57). In our analysis of NHANES 2003–2004, more than one-half the adults who had vitamin C measurements available had a 1-d dietary intake less than the EAR, and those with intake less than the EAR had serum concentrations of vitamin C that were approximately one-third lower than those with adequate dietary intake, and they were 5–10 times more likely to be vitamin C deficient. It should be noted that the dietary intake data were from a single 24-h dietary recall and thus may not provide the best estimate of usual dietary intake.

In prosperous societies, supplement consumption has a significant effect on body stores and circulating concentrations of vitamin C. In NHANES 1999–2000, 52% of adults reported consumption of supplements in the past month, and 35% of adults were regular users of multivitamins (58). Usage rates in children were similar but lower in adolescents. These recent data show increased usage since the overall 40% usage reported during NHANES III (58) and are likely to explain in part the improved vitamin C status of the US population. In NHANES 2003–2004 for those indicating vitamin C supplement use during the preceding month, serum concentrations were 57–73% higher than in
The consequences of vitamin C deficiency in adults range from mild but distinct fatigue and irritability in the absence of manifest scurvy but consistent with latent scurvy were reported by 6 of 7 healthy young men subjected to a vitamin C depletion protocol (60). Latent scurvy is also characterized by nonspecific symptoms such as joint and muscle pain (3). A substantial percentage of adults (16%) in NHANES 2003–2004 had vitamin C concentrations that were associated with low energy and weakness as a result of inadequate intake of vitamin C. More than 20% of adults showed marginal vitamin C status, placing them at risk of vitamin C deficiency, similar to the 20–23% estimates in NHANES III (20). The limitations of the study are several. For the survey comparison, NHANES III data quality was not as good as NHANES 2003–2004. Although the main indicators of data

nonusers. When the relation between age and vitamin C status was examined in supplement users and nonusers, older persons (≥60 y) had better vitamin C status in part because of supplement use. A frequency analysis of smoking by supplement usage in this population showed that those aged ≥60 y who did not use supplements were more likely to be smokers than those who did (22% compared with 12%). Smoking accelerates vitamin C turnover and lowers serum concentrations. Although older women are more likely to consume fruit and vegetables than their younger counterparts, accounting for some of the improvement in the oldest age group, older men are not (59). Even so, a substantial minority (10%) of older men and women consume far less vitamin C than the Recommended Dietary Allowance through dietary sources (59).

The consequences of vitamin C deficiency in adults range from petechial hemorrhages, follicular hyperkeratoses with unerupted corkscrew hairs, anemia, bleeding gums, and loosened teeth to more subtle changes in mood and affect which might become apparent before the body is fully depleted. Mild but distinct fatigue and irritability in the absence of manifest scurvy but consistent with latent scurvy were reported by 6 of 7 healthy young men subjected to a vitamin C depletion protocol (60). Latent scurvy is also characterized by nonspecific symptoms such as joint and muscle pain (3). A substantial percentage of adults (16%) in NHANES 2003–2004 had vitamin C concentrations that were associated with low energy and weakness as a result of inadequate intake of vitamin C. More than 20% of adults showed marginal vitamin C status, placing them at risk of vitamin C deficiency, similar to the 20–23% estimates in NHANES III (20). The limitations of the study are several. For the survey comparison, NHANES III data quality was not as good as NHANES 2003–2004. Although the main indicators of data

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### Table 4

Serum vitamin C deficiency (<11.4 µmol/L) of persons in different age or race-ethnic groups, stratified by sex, with upper (UL) and lower (LL) 95% confidence limits in the United States, for 1988–1994 and 2003–2004.

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1. Confidence limits were constructed with the arc-sine transformation (32). Data for 1988–1994 were based on the third National Health and Nutrition Examination Survey (NHANES).
2. Equality of percentages between survey periods (2003–2004 and 1988–1994) were tested on the arc-sine scale by using the Student’s t statistic with 15 df.
3. Includes all race-ethnic categories.
4. Percentages were age-adjusted by using the direct method to the year 2000 US census population estimates with the use of age groups 6–11, 12–19, 20–39, 40–59, and ≥60 y (35).
5. Percentages were age-adjusted by using the direct method to the year 2000 US census population estimates with the use of age groups 20–39, 49–59 y, and ≥60 y (35).
6. Relative SE = (SE of the percentage/percentage) × 100 >40% (39).
7. Relative SE = (SE of the percentage/percentage) × 100 <30% but ≥40% (39).
8. Significantly different from females in respective age group, P < 0.05 (Student’s t statistic with 15 df).
9. Race and ethnicity were self-reported.
10. Significantly different from women in respective race-ethnic group, P < 0.05 (Student’s t statistic with 15 df).
quality (bench QC pools) were acceptable, the blind QC pools and split sample data were not optimal. For this reason a more extensive analysis of the mean concentrations of vitamin C in various subgroups was not undertaken, but rather we limited our comparison to prevalence of deficiency. To compare surveys it was necessary to adjust the NHANES III data set to make it comparable to the NHANES 2003–2004 survey method. Improvements in the assay were made in the period between the two surveys. Consumable supplies were shown to contain materials that measurably degrade vitamin C within a short period of time (<24 h) (61). It was suggested that this degradation may occur in autosampler vials, tubes, and vials used in the collection and processing of blood and serum samples and that this type of degradation may account for a substantial amount of the observed interlaboratory variation in NIST-sponsored exercises for vitamin C measurement. Two features of the assay used for NHANES 2003–2004 were designed to mitigate effects of oxidation and degradation, namely, use of an internal standard that partially compensated for procedural losses during the assay and calibrators that were processed the same as samples such that both were exposed to similar conditions during the processing and analysis steps. Overall, ~3% of the difference in mean serum concentrations between survey periods can be explained by method bias. This amount of bias is considered clinically acceptable, considering other sources of error in measuring serum vitamin C such as analytic error (CV_A = 5–9%), within-individual variation for repeated measurements (CV_I = 26%), and variation of the group or population for this analyte (CV_G = 3%)(62,63). A complication in interpreting vitamin C serum and dietary intake data, ordinarily considered the sum of intake from fruit, vegetables, supplements, and fortified foods, is the availability of D-ascorbic acid, which is used as a preservative in prepared foods. The HPLC method used in this analysis (and during NHANES III) does not distinguish between the D- and L-isomers, which probably do not share full biological activity (1). A significant amount of D-ascorbate is found in some prepared foods, particularly cured meats where it is used to shorten processing time and improve the color.

The strengths of this study are numerous. These results are from a national survey to measure vitamin C with the use of

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1 Includes all race-ethnic categories; age-adjusted by the direct method to the year 2000 US census population estimates with the use of age groups 20–39, 40–59, and ≥60 y (35). Confidence limits were constructed with the arc-sine transformation (32). Data for 1988–1994 were based on data from the third National Health and Nutrition Examination Survey (NHANES).

2 Equality of percentages between survey periods (2003–2004 and 1988–1994) were tested on the arc-sine scale (Student’s t statistic with 15 df).

3 Smoker is defined as having serum cotinine > 10 ng/mL; nonsmoker has cotinine ≤10 ng/mL.

4 Significantly different from smokers in respective sex groups, P < 0.05 (Student’s t statistic with 15 df).

5 Defined as poverty-income ratio (PIR) of <1 (low), 1 to <3 (medium), or ≥3 (high).

6 NHANES 2003–2004: percentage deficient decreased linearly with increasing PIR, 7

7 NHANES 2003–2004: percentage deficient decreased linearly with increasing PIR, 8

8 Significantly different from low PIR, P < 0.01 (Student’s t statistic with 15 df).
a specific and sensitive HPLC method. Estimated prevalence rates of deficiency are based on serum concentrations of vitamin C, not from dietary recall. The quality of the NHANES 2003–2004 laboratory data were excellent as judged by all relevant quality assurance indicators. NHANES focuses on noninstitutionalized persons, whereas nutritional data in the elderly are often limited to those who are not community dwelling.

In conclusion, the vitamin C status of the US population appears to have substantially improved from 1988–1994 to 2003–2004. Nevertheless, the prevalence of vitamin C deficiency in various subgroups remains a concern, considering the wide availability of vitamin C in common fruit and vegetables, as well as in fortified foods and beverages.

We thank the staff of the Nutritional Biomarkers Branch who worked on vitamin C testing past and present, including Mary Xu who measured serum vitamin C concentrations and Huiping Chen who reviewed the data for quality assurance. The authors' responsibilities were as follows—RLS and DAL: data review; MDC: statistical analysis; and RLS and MDC: writing of the manuscript. All authors interpreted data and critically revised the manuscript. None of the authors had a conflict of interest.

REFERENCES


TABLE 6
Serum vitamin C deficiency (<11.4 μmol/L) of persons aged ≥20 y in different categories of supplement use or dietary intake, stratified by sex, with upper (UL) and lower (LL) 95% confidence limits in the United States, 1988–1994 and 2003–2004

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<td>Nonusers</td>
<td>1211</td>
<td>11.2‡</td>
</tr>
<tr>
<td>Vitamin C dietary intake§</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greater than or equal to the EAR</td>
<td>816</td>
<td>3.0</td>
</tr>
<tr>
<td>Less than the EAR</td>
<td>1227</td>
<td>15.0§</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greater than or equal to the EAR</td>
<td>1011</td>
<td>1.0</td>
</tr>
<tr>
<td>Less than the EAR</td>
<td>1159</td>
<td>10.8§</td>
</tr>
</tbody>
</table>

† Includes all race-ethnic categories; age-adjusted by using the direct method to the year 2000 US census population estimates with the use of age groups 20–39, 49–59, and ≥60 y (35). Confidence limits were constructed with the arc-sine transformation (32). Data for 1988–1994 were based on data from the third National Health and Nutrition Examination Survey (NHANES). EAR, Estimated Average Requirement.

‡ Equality of percentages between survey periods (2003–2004 and 1988–1994) were tested on the arc-sine scale tested with Student's t statistic with 15 df.

§ A supplement user is defined as having taken one or more vitamin C–containing supplements during the previous 30 d.

¶ Significantly different from vitamin C supplement users in respective sex group, P < 0.05 (Student's t statistic with 15 df).

§ Based on a single 24-h recall interview; defined as the daily intake that is estimated to meet the requirement in one-half of apparently healthy persons in a life-stage or sex group (31).

†§ Significantly different from those with vitamin C intake greater than or equal to the EAR in respective sex group, P < 0.05 (Student's t statistic with 15 df).