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Original Contribution

Vitamin C Deficiency in a Population of Young Canadian Adults

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A cross-sectional study of the 979 nonsmoking women and men aged 20–29 years who participated in the Toronto Nutrigenomics and Health Study from 2004 to 2008 was conducted to determine the prevalence of serum ascorbic acid (vitamin C) deficiency and its association with markers of chronic disease in a population of young Canadian adults. High performance liquid chromatography was used to determine serum ascorbic acid concentrations from overnight fasting blood samples. A 1-month, 196-item food frequency questionnaire was used to assess dietary intakes. Results showed that 53% of subjects had adequate, 33% had suboptimal, and 14% had deficient levels of serum ascorbic acid. Subjects with deficiency had significantly higher measurements of mean C-reactive protein, waist circumference, body mass index, and blood pressure than did subjects with adequate levels of serum ascorbic acid. The odds ratio for serum ascorbic acid deficiency was 3.43 (95% confidence interval: 2.14, 5.50) for subjects who reported not meeting the recommended daily intake of vitamin C compared with those who did. Results suggest that 1 of 7 young adults has serum ascorbic acid deficiency, in part, because of unmet recommended dietary intakes. Furthermore, serum ascorbic acid deficiency is associated with elevated markers of chronic disease in this population of young adults, which may have long-term adverse health consequences.

ascorbic acid; biological markers; chronic disease; ethnic groups; scurvy

Abbreviation: RDA, recommended dietary allowance.

Humans cannot synthesize vitamin C (ascorbic acid) de novo and must obtain this essential nutrient from their diet. Ascorbic acid is required for the synthesis of carnitine, collagen, norepinephrine, and epinephrine (1). Ascorbic acid also inhibits oxidative damage and aids in the conversion of cholesterol to bile acids (2). An inverse relation has been observed between serum ascorbic acid concentrations and risk of cardiovascular disease (3, 4), diabetes (5, 6), and all-cause mortality (7). Serum ascorbic acid is also inversely associated with several markers of chronic disease including glucose homeostasis (5), blood pressure (8, 9), oxidative stress (10, 11), high sensitivity C-reactive protein (12), and indicators of obesity, such as body mass index and the waist/hip ratio (13–16). These studies have all used subjects that are middle aged or older, and the health consequences of having chronically inadequate serum ascorbic acid concentrations at a young age remain unknown.

Serum ascorbic acid concentrations are considered to be adequate if >28 μmol/L, suboptimal if between 11 and 28 μmol/L, and deficient if <11 μmol/L (17, 18), because symptoms of scurvy have been observed just below this level (19). The recommended dietary allowance (RDA) for vitamin C was set at 75 mg/day for nonsmoking, nonpregnant women and 90 mg/day for nonsmoking men in order to achieve adequate levels of serum ascorbic acid. Although dietary intake of vitamin C is the primary determinant of serum ascorbic acid concentrations (16), circulating ascorbic acid concentrations can be influenced by several factors, such as age (20), sex (16, 21), smoking (16, 22), body weight (23, 24), physical activity (13), season (22), dietary iron (25), serum lipids (22), and prior vitamin C depletion (23). Our objective for this study was to determine the prevalence of serum ascorbic acid deficiency and its relation to dietary vitamin C inadequacy in a population of young Canadian adults, as well as to assess

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whether the deficiency is associated with markers of chronic disease.

MATERIALS AND METHODS

Study design and population

Subjects ($n = 1{,}183$) were participants of the Toronto Nutrigenomics and Health Study, which is a cross-sectional examination of free-living women ($n = 825$) and men ($n = 358$) between 20 and 29 years of age recruited from the University of Toronto campus. Individuals did not participate in the study if they could not provide a venous blood sample or if they were pregnant or breastfeeding. Smokers ($n = 82$) were excluded because of the known ascorbic acid-depleting effects of smoking (16, 22). Individuals who may have underreported (<800 kcal/day) or overreported (>3,500 kcal/day for women, >4,000 kcal/day for men) their energy intakes ($n = 85$) were excluded. Subjects were excluded if they had any missing data ($n = 38$). After exclusions, 979 subjects (692 women and 287 men) remained. Vitamin C supplement users ($n = 358$) were identified as anyone who took a vitamin C-containing multivitamin ($n = 67$), a supplement containing vitamin C exclusively ($n = 207$), or both ($n = 84$), and analyses involving dietary vitamin C were conducted both including and excluding these supplement users. Subjects were grouped into 1 of 3 ethnocultural groups: Caucasian, East Asian, and others, which included those with a mix of 2 or more ethnocultural groups. The month that each subject participated in the study was used to classify the subjects by the 4 seasons of spring (March, April, and May); summer (June, July, and August); autumn (September, October, and November); and winter (December, January, and February). The study protocol was approved by the Research Ethics Board at the University of Toronto, and all subjects provided written, informed consent.

Dietary assessment

We used the 196-item, Toronto-modified, Willett food frequency questionnaire to assess habitual food intake over the past month. To improve the measurement of self-reported food intake, each subject was given instructions on how to complete the food frequency questionnaire using visual aids of portion sizes. Subjects' responses to the individual foods were converted to daily number of servings for each item. A vitamin C content value was assigned to a serving of each item on the basis of the nutrient contents of the food in the US Department of Agriculture's database. These vitamin C content values were combined to compute a total daily vitamin C intake for each subject.

Anthropometrics and physical activity

Anthropometric measurements including height, weight, and waist circumference were determined, and body mass index (weight (kg)/height $(m)^2$) was calculated. Resting systolic and diastolic blood pressure measurements were taken by using the OMRON IntelliSense Blood Pressure Monitor (Model HEM-907XL; OMRON Healthcare, Vernon Hills, Illinois). Two measurements were taken, 1 minute apart, and the mean of the 2 consecutive readings was used. Modifiable physical activity was measured by questionnaire and expressed as metabolic equivalent-hours per week, which represents both leisure and occupational activity but does not include sedentary hours of sleeping or sitting. One metabolic equivalent-hour is equal to 1 kcal expended per kg of body weight per hour sitting at rest (26).

Serum ascorbic acid and other biochemical measurements

After a minimum 12-hour overnight fast, blood samples were collected at LifeLabs Medical Laboratory Services (Toronto, Ontario, Canada), where all of the biochemical measurements reported in the present study were performed. For the serum ascorbic acid measurement, 100 μL of serum from each subject were aliquotted into an amber tube to protect against light before being frozen at −20°C for a minimum of 24 hours. Once thawed, 50 μL of salicylsalicylic acid were added as a deproteinizing agent and centrifuged for 1 minute. Fifty μL of the protein-free supernatant were then mixed with 2 mL of the stabilizer 0.1% metaphosphoric acid, and the total serum ascorbic acid concentration was measured by high performance liquid chromatography along with certified controls (National Institute of Standards and Technology Standard Reference Material 970, Levels I and II). Standards and calibrators were prepared from L-ascorbic acid (Tissue Culture Grade) at concentrations that ranged from 6.25 to 100 μmol/L. All samples that were measured to be 80 μmol/L or more were repeated.

Glucose, total cholesterol, and high density lipoprotein cholesterol were measured by using a chromatographic enzymatic method with a Siemens Advia 2400 analyzer (Siemens Healthcare Diagnostics, Deerfield, Illinois). Insulin was measured by using a chemiluminescent immunometric method with a Siemens Immulite 2000 analyzer (Siemens Healthcare Diagnostics). After converting insulin concentrations in pmol/L to μU/mL, the homeostasis model of insulin resistance was calculated by using the formula: (insulin × glucose)/22.5, and the homeostasis model of beta-cell function was calculated by using the formula: (20 × insulin)/(glucose − 3.5).

Statistical analysis

All statistical analyses were performed by using Statistical Analysis Systems software (SAS, version 9.1; SAS Institute, Inc., Cary, North Carolina). Significant P values are 2 sided and less than 0.05. Characteristics of subjects were compared among serum ascorbic acid status groups by using χ^2 tests for categorical variables and analysis of variance for continuous variables with a Bonferroni adjustment. Mean serum ascorbic acid concentrations, crude and adjusted, were compared between women and men, major ethnocultural groups, oral contraceptive users and nonusers, body mass index category groups, dietary vitamin C category groups, and supplement users and nonusers. These comparisons were first made by using an unpaired t test

for dichotomous variables and an analysis of variance and Bonferroni adjustment for variables with more than 2 levels. Polytomous logistic regression was used to compute odds ratios and 95% confidence intervals. Partial Pearson correlations and general linear models were used to examine the association between dietary vitamin C and serum ascorbic acid concentrations. The dietary vitamin C variable was slightly skewed; therefore, the *r* and *P* values for slope are displayed from analyses in which the dietary vitamin C variable is log transformed, but the β and standard error are displayed without log-transformation to facilitate interpretation.

The adjusted model used in analyses included sex, body mass index, ethnocultural group, high sensitivity C-reactive protein, oral contraceptive use (women only), and season, as determined by stepwise linear regression and an analysis of covariance at a 0.05 significance level. No interactions between these covariates and dietary vitamin C on serum ascorbic acid concentrations were observed. Energy intake was also a covariate when the vitamin C diet-serum association was examined. A number of other covariates were considered as potential confounders, including intakes of carotenoids, tocopherols, flavonoids, iron, fiber, and alcohol; serum lipid concentrations; blood pressure; and physical activity. However, none was statistically significant or materially altered the results, and so these variables were not included in the final model.

RESULTS

As shown in Table 1, 53% of subjects had adequate (>28 μmol/L), 33% had suboptimal (11–28 μmol/L), and 14% had deficient (<11 μmol/L) levels of serum ascorbic acid. The subjects with deficient serum ascorbic acid had a higher mean serum concentration of high sensitivity C-reactive protein (2.04 mg/L) than did subjects with adequate serum ascorbic acid (1.03 mg/L) ($P = 0.017$). Waist circumference, body mass index, and diastolic blood pressure measurements were also higher in subjects with deficient serum ascorbic acid than in subjects with adequate serum ascorbic acid concentrations.

Multivariate-adjusted serum ascorbic acid concentrations were higher in women than in men (30.0 vs. 24.4 μmol/L) ($P < 0.0001$) (Table 2), although intake levels of vitamin C were similar for both women and men (248.1 vs. 227.7 mg/day) ($P = 0.26$). Women who were taking oral contraceptive pills had a lower serum ascorbic acid concentration (27.4 μmol/L) than women who were not (32.4 μmol/L) ($P = 0.004$). Subjects with a body mass index ≥25 had a significantly lower mean serum ascorbic acid concentration than did subjects with a body mass index <25 according to the unadjusted model (27.6 vs. 31.4 μmol/L) ($P = 0.003$); however, this effect was no longer significant with the adjusted model (26.0 vs. 27.6 μmol/L) ($P = 0.26$). Further analysis indicated that the absence of a significant difference was due solely to the adjustment for high sensitivity C-reactive protein and not to any of the other covariates.

The risk of suboptimal and deficient serum ascorbic acid in relation to dietary vitamin C is described in Table 3 with the adequate serum ascorbic acid group serving as the control. The multivariate-adjusted odds ratio for serum ascorbic acid deficiency was 3.43 (95% confidence interval: 2.14, 5.50) for subjects who reported not meeting the RDA of vitamin C compared with those who met the requirement. The risk of serum ascorbic acid deficiency was 2.7-fold for women but more than 5-fold for men. Compared with subjects who reported meeting the RDA for dietary vitamin C, subjects who reported dietary vitamin C intakes below the RDA did not have a significantly higher risk of having suboptimal (11–28 μmol/L) serum ascorbic acid concentrations.

Associations between dietary and serum vitamin C are presented in Table 4. The Pearson correlation was 0.13 ($P = 0.007$) for women and 0.27 ($P < 0.0001$) for men. A significant association was observed between dietary and serum vitamin C, regardless of whether supplement users were included (0.06 μmol/L of ascorbic acid per 10 mg of dietary vitamin C; $P < 0.0001$) or excluded (0.37 μmol/L of ascorbic acid per 10 mg of dietary vitamin C; $P < 0.0001$).

DISCUSSION

Our study determined the prevalence of serum ascorbic acid deficiency in a population of young adults recruited from a large university campus in Canada. Although the majority of subjects (53%) had adequate serum ascorbic acid concentrations, nearly 1 of 3 subjects had suboptimal (11–28 μmol/L) serum ascorbic acid, and 1 of 7 was deficient (<11 μmol/L) (18). Our findings are comparable to data from the Third National Health and Nutrition Examination Survey (NHANES) in the United States, which revealed deficiency rates of 13% for males and 11% for females aged 18–24 years (27). To our knowledge, the only other study to report the prevalence of serum ascorbic acid deficiency among Canadians examined a sample of hospitalized patients with a mean age above 65 years, where 19% were found to be deficient (28).

Consistent with previous findings (16, 29), the mean serum ascorbic acid concentrations that we report are higher in women than in men. The reason for this difference between men and women remains unknown but does not appear to be due to dietary vitamin C, because intake levels were not different between men and women. In our study, one third of the female subjects reported using oral contraceptives, and serum ascorbic acid concentrations were significantly lower in women taking oral contraceptives than in those who were not. However, the vitamin C intake did not differ between the 2 groups (data not shown) in this population of nonsmokers, suggesting that hormones might influence vitamin C metabolism.

The estimated vitamin C intakes from dietary sources for men and women that we report in the present study are similar to values reported in other studies (30, 31). In our population, 17% reported vitamin C intakes below the RDA, which is similar to findings from the Canadian Community Health Survey, where 10%–25% of men and women aged 19–30 years report a usual vitamin C intake that is below the RDA (30).

Table 1. Characteristics of Women and Men Aged 20–29 Years by Serum Ascorbic Acid Concentration Adequacy Status, Toronto Nutrigenomics and Health Study, 2004–2008[a]

Characteristic	Serum Ascorbic Acid Concentration									*P* Value
	Deficient (<11 μmol/L)			Suboptimal (11–28 μmol/L)			Adequate (>28 μmol/L)			
	Mean (SE)	No.	%	Mean (SE)	No.	%	Mean (SE)	No.	%	
Total		133	14		325	33		521	53	
Sex										0.03
Women		87	65		218	67		387	74	
Men		46	35		107	33		134	26	
Age, years	22.8 (0.2)			22.9 (0.1)			22.5 (0.1)			0.10
Ethnocultural group										0.19
Caucasian		56	42		163	50		252	58	
East Asian		45	34		105	32		191	37	
Other		32	24		57	18		78	15	
Season										0.008
Spring		35	26		104	32		119	23	
Summer		42	32		87	27		132	25	
Autumn		29	22		78	24		175	34	
Winter		27	20		56	17		95	18	
Physical activity, MET-hours/week	7.4 (0.3)			7.8 (0.2)			7.6 (0.1)			0.25
Body mass index, kg/m^2	23.1 (0.1)			23.0 (0.2)			22.3 (0.2)			0.007[b]
Waist circumference, cm	75.0 (0.7)			74.6 (0.5)			72.8 (0.4)			0.003[b]
Oral contraceptive use (women only)										0.003[c]
Yes		40	46		73	33		107	28	
No		47	54		145	67		280	72	
Systolic blood pressure, mm Hg	114.8 (1.0)			114.7 (0.6)			113.0 (0.5)			0.06
Diastolic blood pressure, mm Hg	70.2 (0.7)			69.6 (0.4)			68.2 (0.4)			0.004[b]
HOMA-IR	1.6 (0.1)			1.4 (0.1)			1.4 (0.1)			0.19
HOMA-beta	117.3 (6.6)			110.4 (4.2)			110.0 (3.3)			0.66
Insulin, pmol/L	54.3 (3.1)			47.8 (2.0)			48.0 (1.6)			0.17
Total cholesterol, mmol/L	4.16 (0.06)			4.23 (0.04)			4.24 (0.03)			0.58
Total cholesterol:HDL-C ratio	2.74 (0.06)			2.85 (0.04)			2.77 (0.03)			0.22
High-sensitivity C-reactive protein, mg/L	2.04 (0.23)			1.46 (0.15)			1.03 (0.12)			0.0004[c]
Serum ascorbic acid, μmol/L	6.2 (0.9)			21.0 (0.6)			42.9 (0.4)			<0.0001[d]
Dietary vitamin C, mg/day										
All subjects	178.6 (22.8)			230.7 (14.6)			265.4 (11.5)			0.002[e]
No supplement users	107.0 (9.0)			146.0 (5.9)			144.4 (4.9)			0.0005[f]
Dietary vitamin C adequacy										<0.0001[f]
Meets RDA[g]		90	68		269	83		454	87	
Less than RDA		43	32		56	17		67	13	
Supplement use[h]										0.03
Yes		39	30		110	34		209	40	
No		94	70		215	66		312	60	
Fruit, servings/day	2.0 (0.2)			2.8 (0.1)			2.9 (0.1)			<0.0001[f]
Vegetables, servings/day	2.8 (0.2)			3.4 (0.1)			3.5 (0.1)			0.007[f]
Iron, mg/day	17.5 (1.6)			19.0 (1.0)			21.4 (0.8)			0.05
Energy, calories/day	1,820 (54)			1,987 (36)			1,960 (28)			0.03[i]
Alcohol, g/day	5.3 (0.7)			5.3 (0.5)			4.8 (0.4)			0.69

Abbreviations: HDL-C, high density lipoprotein cholesterol; HOMA-beta, homeostasis model of beta-cell function; HOMA-IR, homeostasis model of insulin resistance; MET, metabolic equivalent; RDA, recommended dietary allowance; SE, standard error.

[a] Differences between ascorbic acid status groups were compared by using an analysis of variance for continuous variables and a chi-square test for categorical variables.

[b] (Deficient, suboptimal) > adequate after Bonferroni correction ($P < 0.0167$).

[c] Deficient > adequate after Bonferroni correction ($P < 0.0167$).

[d] Adequate > suboptimal > deficient after Bonferroni correction ($P < 0.0167$).

[e] Adequate > deficient after Bonferroni correction ($P < 0.0167$).

[f] (Adequate, suboptimal) > deficient after Bonferroni correction ($P < 0.0167$).

[g] RDA: 75 mg of vitamin C/day for nonsmoking women; 90 mg of vitamin C/day for nonsmoking men.

[h] Supplement usage includes the use of vitamin C supplements and vitamin C-containing multivitamins.

[i] Suboptimal > deficient after Bonferroni correction ($P < 0.0167$).

Table 2. Mean Serum Ascorbic Acid Concentration of Women and Men Aged 20–29 Years Together and Stratified by Sex, Ethnocultural Group, Oral Contraceptive Use, Body Mass Index, High Sensitivity C-reactive Protein, and Dietary Vitamin C and Supplement Use, Toronto Nutrigenomics and Health Study, 2004–2008

	No.	Serum Ascorbic Acid (μmol/L)			
		Crude Model[a]		Adjusted Model[b]	
		Mean (SE)	*P* Value	Mean (SE)	*P* Value
All subjects	979	30.6 (0.6)		27.2 (0.9)	
Sex			<0.0001		<0.0001
Women	692	33.4 (0.7)		30.0 (0.9)	
Men	287	28.9 (0.9)		24.4 (1.3)	
Ethnocultural group			0.88		0.25
Caucasian	471	31.2 (0.8)		30.7 (0.8)	
East Asian	341	31.4 (0.9)		29.3 (1.0)	
Oral contraceptive use (women only)			<0.0001		0.004
No	472	33.9 (0.8)		32.4 (1.0)	
Yes	220	28.1 (1.1)		27.4 (1.4)	
Body mass index, kg/m^2			0.003		0.26
<25	787	31.4 (0.6)		27.6 (1.0)	
≥25	192	27.6 (1.1)		26.0 (1.5)	
Season			<0.0001[c]		0.0002[c]
Spring	258	28.1 (1.1)		24.9 (1.3)	
Summer	261	28.9 (1.0)		25.7 (1.3)	
Autumn	282	34.2 (1.0)		30.6 (1.2)	
Winter	178	31.3 (1.3)		27.6 (1.4)	
High-sensitivity C-reactive protein, mg/L			<0.0001		0.03
≤3	871	31.4 (0.6)		27.4 (1.0)	
>3	108	24.8 (1.5)		23.3 (1.3)	
Dietary vitamin C adequacy			<0.0001		<0.0001
Meets RDA[d]	813	31.9 (0.6)		28.6 (1.0)	
Less than RDA	166	24.4 (1.3)		21.6 (1.5)	
Supplement use[e]			0.02		0.03
No	621	29.6 (0.7)		26.4 (1.0)	
Yes	358	32.4 (0.9)		28.7 (1.2)	

Abbreviations: RDA, recommended dietary allowance; SE, standard error.

[a] For the crude model, means were compared by using a *t* test for dichotomous variables and an analysis of variance with Bonferroni correction for variables with more than 2 levels.

[b] For the adjusted model, a general linear model was used that adjusted for sex, ethnocultural group, body mass index, oral contraceptive use, high sensitivity C-reactive protein, and season.

[c] Autumn > (spring, summer) after Bonferroni correction ($P < 0.0167$).

[d] RDA: 75 mg of vitamin C/day for nonsmoking women; 90 mg of vitamin C/day for nonsmoking men.

[e] Supplement usage includes the use of vitamin C supplements and vitamin C-containing multivitamins.

We observed an inverse association between serum ascorbic acid concentrations and 2 measures of obesity (body mass index and waist circumference), which is consistent with previous studies of older adults (14–16). Vitamin C is an essential cofactor in the biosynthesis of carnitine (13), a molecule required for the oxidation of fatty acids, and marginal vitamin C status has been associated with reduced fat oxidation (13). Other predictors of chronic disease that we found to be inversely associated with serum ascorbic acid include high sensitivity C-reactive protein and blood pressure. A recent study of young women aged 18–21 years also found blood pressure to be inversely associated with serum ascorbic acid (32).

Dietary vitamin C and serum ascorbic acid were positively correlated, agreeing with previous studies demonstrating that dietary vitamin C is the major determinant of serum ascorbic acid (23, 33). Compared with subjects who met the RDA for dietary vitamin C, subjects who did not meet the RDA had more than a 3-fold greater likelihood of having serum ascorbic acid deficiency. This finding indicates that serum ascorbic acid deficiency would have been much less prevalent if more subjects met the RDA for

Table 3. Odds Ratios and 95% Confidence Intervals for Suboptimal and Deficient Serum Ascorbic Acid in Relation to Meeting the Recommended Dietary Allowance for Dietary Vitamin C in Women and Men Aged 20–29 Years, Toronto Nutrigenomics and Health Study, 2004–2008[a]

Dietary Vitamin C[b,c]	Serum Ascorbic Acid Concentration										
	Adequate, no.	Suboptimal					Deficient				
		No.	Crude		Adjusted		No.	Crude		Adjusted	
			Odds Ratio	95% Confidence Interval	Odds Ratio	95% Confidence Interval		Odds Ratio	95% Confidence Interval	Odds Ratio	95% Confidence Interval
All subjects											
Meets RDA	454	269	1.00		1.00		90	1.00		1.00	
Less than RDA	67	56	1.41	0.96, 2.07	1.41	0.95, 2.10	43	3.24	2.08, 5.05	3.43	2.14, 5.50
Women											
Meets RDA	347	187	1.00		1.00		68	1.00		1.00	
Less than RDA	40	31	1.44	0.87, 2.38	1.53	0.91, 2.55	19	2.42	1.32, 4.44	2.73	1.46, 5.12
Men											
Meets RDA	107	82	1.00		1.00		22	1.00		1.00	
Less than RDA	27	25	1.21	0.61, 2.13	1.36	0.72, 2.56	24	4.32	2.11, 8.85	5.06	2.33, 10.98
Caucasians											
Meets RDA	230	138	1.00		1.00		40	1.00		1.00	
Less than RDA	22	25	1.89	1.03, 3.49	1.89	1.01, 3.53	16	4.18	2.12, 8.65	4.53	2.10, 9.78
East Asians											
Meets RDA	159	85	1.00		1.00		27	1.00		1.00	
Less than RDA	32	20	1.17	0.63, 2.17	1.11	0.58, 2.11	18	3.31	1.63, 6.72	3.25	1.56, 6.81

Abbreviation: RDA, recommended dietary allowance.

[a] The adjusted model is adjusted for sex, ethnocultural group, body mass index, oral contraceptive use, high sensitivity C-reactive protein, and season. There was no interaction effect for sex ($P_{interaction} = 0.26$). The risk of having a suboptimal or deficient serum ascorbic acid concentration is in relation to the group with adequate concentrations, which served as the control.

[b] Meeting the RDA is the reference group for the exposure variable (dietary vitamin C).

[c] RDA: 75 mg of vitamin C/day for nonsmoking women; 90 mg of vitamin C/day for nonsmoking men.

vitamin C of 75 mg/day for women and 90 mg/day for men who are nonsmokers.

Several potential limitations should be considered in interpreting the results of our study. Measurement error associated with the food frequency questionnaire could result in inaccurate reporting of the dietary data. This could lead to misclassification of whether some of the subjects met the RDA for vitamin C or not. Our data indicate that there were subjects with deficient serum ascorbic acid concentrations who reported meeting the RDA for vitamin C, which could be due to factors other than measurement error. Because processing and degradation over time can affect the amount of ascorbic acid in food (34), the regular consumption of fruit and vegetables that are heavily processed or close to expiration could lead to an available amount of dietary vitamin C that is lower for these subjects than the dietary vitamin C value indicated in the nutrient database. Furthermore, it is possible that some individuals have a requirement that exceeds the RDA because of genetic or lifestyle factors that influence ascorbic acid utilization. Alternatively, some subjects may have overestimated their vitamin C intake because of the social desirability of reporting consumption of fruits and vegetables that are considered healthy. However, estimated vitamin C intakes for men and women in our study are comparable to those reported in previous studies (30, 31), especially when supplement users are excluded. A 1-month food frequency questionnaire was used to assess dietary vitamin C intake because the half-life of ascorbic acid in humans is approximately 16 days (35) and, when dietary vitamin C is eliminated, ascorbic acid becomes undetectable in the blood after 35–40 days (36). The shorter time frame of 1 month as compared with a longer duration should also be more accurate at capturing seasonal differences in vitamin C intake (37, 38), because at least 90% of the vitamin C in the diet comes from fruits and vegetables (33), many of which are available seasonally. We chose the Willett food frequency questionnaire for our study because it has been extensively used and validated in North America (39).

We recognize that the validity of our results depends highly on the reliability of the method used to measure serum ascorbic acid. We used the same laboratory that services numerous physicians across Canada and employs high performance liquid chromatography along with standards from the National Institute of Standards and Technology to ensure accuracy in the determination of serum ascorbic acid concentrations. Although only a single measurement of serum ascorbic acid was used, a study measuring the intra-individual variability of blood concentrations of ascorbic

Table 4. Association Between Dietary Vitamin C and Serum Ascorbic Acid in Women and Men Aged 20–29 Years, Toronto Nutrigenomics and Health Study, 2004–2008[a]

	No.	Pearson's Correlation (*r*)	Slope (β)[b] (SE)	*P* Value
Crude model				
All subjects	979	0.17	0.07 (0.01)	<0.0001
No supplement users	621	0.19	0.30 (0.07)	<0.0001
Women	692	0.13	0.05 (0.03)	0.0009
Men	287	0.30	0.14 (0.03)	<0.0001
Adjusted model				
All subjects	979	0.16	0.06 (0.02)	<0.0001
No supplement users	621	0.20	0.37 (0.08)	<0.0001
Women	692	0.13	0.05 (0.03)	0.007
Men	287	0.27	0.13 (0.03)	<0.0001

Abbreviation: SE, standard error.

[a] Supplement usage includes the use of vitamin C supplements and vitamin C-containing multivitamins. The crude model contains no variables apart from dietary vitamin C and serum ascorbic acid. The adjusted model is adjusted for energy intake, sex, ethnocultural group, body mass index, oral contraceptive use, high sensitivity C-reactive protein, and season. The slopes for men and women were not significantly different from each other ($P_{interaction} = 0.07$). *P* values for slope are displayed from analyses in which the dietary vitamin C variable is log transformed, but the β and standard error are displayed without log transformation to facilitate interpretation.

[b] Slope is presented as the μmol/L of serum ascorbic acid per 10 mg of dietary vitamin C.

acid found that only one ascorbic acid measurement is needed to ensure that the observed correlation is within 10% of the true correlation (40).

Another potential limitation is the absence of information on history of vitamin C depletion, because previous studies have shown that prior vitamin C depletion partially determines vitamin C dose-concentration curves (23). This may have resulted in attenuated correlation coefficients, but it would have no impact on our prevalence estimates of deficiency. Finally, subjects were recruited from a university campus and may not be representative of all young Canadian adults. However, the prevalence of deficiency that we observed is similar to what has been reported from National Health and Nutrition Examination Survey data of American men and women aged 18–24 years who were representative of the entire population (27).

In conclusion, in this cross-sectional study of Canadian men and women aged 20–29 years, 1 of 7 of the young Canadian adults had serum ascorbic acid deficiency, and only 53% had adequate serum ascorbic acid. An inverse association between serum ascorbic acid and markers of chronic disease was already present in these young adults, suggesting potential adverse health effects. The implications of these findings underscore the importance of obtaining the RDA for dietary vitamin C in order to decrease the prevalence of serum ascorbic acid deficiency in young Canadians and to potentially decrease the risk of long-term adverse health effects.

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