

Relationship between dietary intake and plasma concentrations of carotenoids in premenopausal women: application of the USDA-NCI carotenoid food-composition database^{1,2}

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ABSTRACT The diet-plasma relationships for carotenoids were examined in a group of 98 nonsmoking premenopausal women who participated in the cross-sectional phase of the National Cancer Institute (NCI)-US Department of Agriculture (USDA) diet study on alcohol-hormone metabolism, 1988-90. With use of the newly developed USDA-NCI carotenoid food-composition database, the mean daily intakes of carotenoids were significantly higher when estimated from the food-frequency questionnaire (FFQ) than from the 7-d diet records. Lycopene ($\bar{x} = 0.58$ mmol/L), lutein plus zeaxanthin ($\bar{x} = 0.46$ mmol/L), and β -carotene ($\bar{x} = 0.34$ mmol/L) were the major plasma carotenoids. After adjustment for body mass index, energy and alcohol intakes, and total plasma cholesterol concentration, the following significant correlations ($P < 0.05$) were observed between the diet record and the FFQ-estimated carotenoid intakes and their respective plasma concentrations: α -carotene ($r = 0.58$ vs 0.49), β -carotene ($r = 0.51$ vs 0.49), β -cryptoxanthin ($r = 0.49$ vs 0.36), lutein plus zeaxanthin ($r = 0.31$ vs 0.37), lycopene ($r = 0.50$ vs 0.26), and total carotenoids ($r = 0.57$ vs 0.49). These data indicate that plasma carotenoid concentrations are reflective of dietary intake, but the magnitude of the correlation varies depending on the specific carotenoid and on the dietary assessment tool. *Am J Clin Nutr* 1994;60:223-30.

KEY WORDS Carotenoids, dietary assessment, plasma

Introduction

Several epidemiologic studies have provided substantial evidence for an inverse relationship between dietary intake of carotenoid-rich foods and cancer of epithelial sites, particularly lung cancer (1). Until recently most of the attention has been centered on β -carotene, because its blood concentration has also been found to be inversely related to the cancer risk (2-6). With the current availability of the sensitive HPLC technique of carotenoid quantitation, several other carotenoids such as lycopene and lutein have been identified in higher concentrations than that of β -carotene in human serum and plasma (7-10). These major circulating carotenoids, which possess antioxidant capabilities similar to or greater than that of β -carotene, may also be protective against cancer (11, 12). However, because of limited food-

composition data, little is known about the relationships between the dietary intakes of the specific carotenoids and their respective blood concentrations or disease risk.

A carotenoid food-composition database containing values for five specific carotenoids was recently developed by the Nutrient Composition Laboratory, Beltsville Human Nutrition Research Center, US Department of Agriculture (USDA), and the National Cancer Institute (NCI) (13, 14). This database was used to examine the diet-plasma relationships for α -carotene, β -carotene, β -cryptoxanthin, lutein plus zeaxanthin, and lycopene in a group of premenopausal women. The objectives of this study were to 1) assess the dietary intake of specific carotenoids by using a 7-d diet record and a food-frequency questionnaire (FFQ), and 2) compare the diet-plasma carotenoid relationships between the two dietary-assessment tools.

Subjects and methods

Study subjects

The subjects were drawn from a group of women who participated in the 1-mo cross-sectional phase of the NCI-USDA diet study on alcohol and hormone metabolism between 1988 and 1990 (15). These 117 premenopausal and nonsmoking women underwent a screening examination that included a medical history, physical examination, and routine blood biochemistry profile. All subjects gave informed consent and the study was approved by the Institutional Review Boards of the National Cancer Institute and Georgetown University School of Medicine.

Of the 117 screened subjects, 114 met the following study criteria: 1) in good health with normal lipid metabolism; 2) within

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TABLE 1
Characteristics of study subjects¹

	$\bar{x} \pm SD$	Median	Range	Geometric \bar{x}
Age (y)	28.6 \pm 5.1	28.5	20–39	28.2
Body mass index ²	22.8 \pm 3.9	22.0	16.2–37.1	22.4
Plasma lipids (mmol/L)				
Total cholesterol	4.2 \pm 0.8	4.1	2.5–6.8	4.1
HDL	1.6 \pm 0.3	1.6	1.0–2.2	1.6
LDL	2.2 \pm 0.7	2.2	0.7–4.6	2.1
Triglycerides	0.8 \pm 0.4	0.7	0.4–2.6	0.8

¹ *n* = 98 women.

² In kg/m².

85% and 130% of the 1983 Metropolitan Life Insurance desirable weight-for-height; 3) not taking oral contraceptives, not pregnant, and not breast-feeding within the year before the study; and 4) not following a restricted diet. For the analyses performed in the current study, 16 subjects were excluded for the following reasons: missing diet records (*n* = 8) or FFQs (*n* = 1); failing the edit program (*n* = 5) of the Health Habits and History Questionnaire, which identifies potential dietary recall and recording errors (16); and reports of sick days on diet records (*n* = 2). The characteristics of the 98 remaining subjects, aged 20–39 y, are presented in Table 1. Although none of the subjects was taking prescription medications or β -carotene supplements, regular daily use of a multivitamin supplement was reported by 21%, whereas an additional 26% reported irregular use. Furthermore, 91% of the subjects had their dietary and blood data collected during fall and winter.

Dietary assessment

During the 1-mo cross-sectional phase in the free-living state, dietary data were collected by using diet records and an FFQ. Seven consecutive days of diet records were completed by the subjects (except for one with 5 d and one with 6 d) on days 14 through 20 of the menstrual cycle. Subjects were asked to record the intake and amount of any foods, ingredients, and beverages

consumed, and this information was checked daily by a registered dietitian.

All subjects completed a self-administered Health Habits and History Questionnaire, which has an FFQ component enquiring about the use of multivitamin-mineral supplements and the usual frequency of consumption of 100 items of single and multiingredient foods during the past year (16, 17). The usual portion sizes were reported as small, medium, or large with reference to a stated medium serving for each food item. There were several carotenoid-rich items distributed in the different sections of the FFQ: 12 fruits and juices; 17 vegetables; 1 vegetable tomato-based soup; 2 tomato-based dishes of spaghetti, lasagna, other pasta, and pizza; 1 tomato-based sauce; and 1 mixed meat dish with vegetables such as beef stew. These items were listed as single or groups of two or more foods. Furthermore, the subjects were asked to recall additional frequently consumed foods in an open-ended section, and these foods were also used for the computation of the carotenoid intake.

The USDA-NCI carotenoid food-composition database contains values for α -carotene, β -carotene, β -cryptoxanthin, lutein plus zeaxanthin, and lycopene in > 2400 fruits and vegetables and multiingredient foods containing fruits and vegetables (13, 14). The values for the five specific carotenoids were compiled from analytical data that have been critically evaluated by a

TABLE 2
Daily intake of carotenoids, by dietary-assessment tool¹

Carotenoid	$\bar{x} \pm SD$	Median	Range	Geometric \bar{x}
μg				
Diet records				
α -Carotene	573 \pm 590	397	19–3819	365
β -Carotene	2652 \pm 2336	2098	365–16 507	1998
β -Cryptoxanthin	30 \pm 40	21	0–304	16
Lutein	1860 \pm 1543	1217	227–8289	1339
Lycopene	3056 \pm 2608	2392	405–15 605	2208
Total	8171 \pm 4998	6883	1550–30 686	6634
Food-frequency questionnaire				
α -Carotene	746 \pm 685	553	41–3840	545
β -Carotene	3335 \pm 2154	2704	265–11 197	2697
β -Cryptoxanthin	38 \pm 41	29	0.3–260	22
Lutein	2390 \pm 1786	1870	228–9566	1808
Lycopene	3353 \pm 1991	3008	323–15 029	2981
Total	9862 \pm 5177	8535	1028–24 527	8103

¹ *n* = 98.

TABLE 3
Comparison of daily intake of carotenoids estimated from food-frequency questionnaire (FFQ) vs diet records (DR)¹

Carotenoid	Relative difference ²	FFQ and DR correlation (r) ³
	%	
α -Carotene	30.2	0.49
β -Carotene	25.8	0.50
β -Cryptoxanthin	26.7	0.43
Lutein	28.5	0.23
Lycopene	9.7	0.37
Total	20.7	0.48

¹ $n = 98$ women.

² $[(\text{FFQ} - \text{DR value})/\text{DR}]100$. All differences are significant, $P < 0.05$ (based on paired t test on \log_e -transformed variables).

³ All Pearson correlations between FFQ and DR are significant, $P < 0.05$.

computerized system for data quality based on five criteria: number of samples, analytical method, sample handling, sampling plan, and analytical quality control (13). The carotenoid content of the multiingredient foods was calculated by aggregating the carotenoid values of the individual carotenoid-rich ingredients identified from the USDA Survey Nutrient Data Base recipe file (Human Nutrition Information Service, USDA, Hyattsville, MD) (14).

The dietary intake of the carotenoids was computed from the diet records in several steps. All carotenoid-rich foods in the diet records were linked to those in the database. For each food, the specific carotenoid value (in $\mu\text{g}/100$ g) was multiplied by the amount in grams divided by 100. This product was next totaled for all foods in each diet record, and was then averaged over the appropriate number of seven, six, or five diet records.

The procedure described previously (18) was used to compute the carotenoid intake from the FFQ, according to the following steps.

1) All the FFQ carotenoid-rich items were linked to the carotenoid food-composition database. For single food items, the carotenoid content was equivalent to the carotenoid profile of the food. For items with more than one food, the carotenoid content was the weighted average of the carotenoid values of each food in the item, where the weights were chosen to be proportional to

the frequency of consumption from the 24-h recalls of a representative population, ie, 20–40-y-old white women from the Second National Health and Nutrition Examination Survey (NHANES II) (19). For example, the consumption of apples, applesauce, and pears was reported by 9%, 0.5%, and 2%, respectively, of this NHANES II subpopulation. Thus, for this multiple food item, the specific carotenoid values for apples, applesauce, and pears were first multiplied by their respective NHANES II frequencies, weighted for race and sex. These products were next summed for the estimation of the specific carotenoid content of the item.

2) For each FFQ item, the specific carotenoid content, as calculated in the first step, was multiplied by its frequency of consumption (per week equivalents) and portion size (in g) on the FFQ, as developed by Block et al (17). This product was divided by 100, totaled across the FFQ items, and then averaged to estimate the daily intake. Finally, in both the diet records and FFQ, all the five specific carotenoids were summed to obtain the daily total carotenoid intake.

Total energy, fat, protein, and alcohol intakes (in g) were estimated from the diet records by the Nutrition Coordinating Center, University of Minnesota. In the FFQ these nutrients were estimated by the Health Habits and History Questionnaire program (16).

Plasma analyses

On days 5–7, 12–15, and 21–23 of the menstrual cycle, 12-h fasting blood samples were collected from each subject in all-plastic tubes containing EDTA, and the plasma was immediately separated by centrifugation at $1400 \times g$ for 20 min at 4 °C. The plasma samples on day five of the menstrual cycle (≈ 9 d before the start of the diet-recording period) were analyzed enzymatically for cholesterol and triglycerides by using Abbott ABA-100 analyzers with reagents supplied by Abbott Diagnostics, Chicago (20). High-density-lipoprotein cholesterol was similarly enzymatically determined after the precipitation of other lipoprotein fractions with heparin-manganese (21). The Friedewald formula (22) was used for the estimation of low-density-lipoprotein cholesterol.

Plasma α -carotene, β -carotene, β -cryptoxanthin, lutein plus zeaxanthin (hereafter referred to as lutein), and lycopene were determined from two blood samples that had been stored at -70 °C for ≤ 2 y. These samples were collected at the beginning and at the end of the diet-recording period: on day 2 and 2 d after the

TABLE 4
Average plasma carotenoid concentrations¹

Carotenoid	$\bar{x} \pm \text{SD}$	Median	Range	Geometric \bar{x}	Samples 1 and 2 correlation (r) ²
	mmol/L	mmol/L	mmol/L	mmol/L	
α -Carotene	0.11 ± 0.08	0.08	0.02–0.40	0.08	0.96
β -Carotene	0.34 ± 0.19	0.29	0.09–0.98	0.30	0.94
β -Cryptoxanthin	0.17 ± 0.05	0.17	0.07–0.33	0.17	0.91
Lutein	0.46 ± 0.15	0.43	0.21–0.88	0.43	0.84
Lycopene	1.58 ± 0.24	0.54	0.22–1.89	0.54	0.80
Total	1.66 ± 0.54	1.57	0.85–3.31	1.57	0.92

¹ $n = 98$ women. Average of plasma samples 1 and 2 collected within 1 wk of each other were used.

² All Pearson correlations between samples 1 and 2 are significant, $P = 0.0001$.

TABLE 5
Ratios of intra- to interindividual variabilities of carotenoid in diet and plasma¹

Carotenoid	Diet records ²	Plasma ³
α -Carotene	4.93	0.04
β -Carotene	4.22	0.04
β -Cryptoxanthin	4.41	0.11
Lutein	5.09	0.20
Lycopene	18.40	0.25
Total	5.92	0.11

¹ $n = 98$ women.

² Based on 7 consecutive days of diet records.

³ Based on two plasma samples collected within 1 wk of each other.

diet-recording period (days 15 and 22 of the menstrual cycle) for 66 subjects; on day 1 and 1 d after the diet-recording period (days 14 and 21 of the menstrual cycle) for 10 subjects; and on varying days, but within 1 wk of each other for the remaining 22 subjects.

The carotenoids were analyzed by HPLC on C₁₈ reversed-phase and silica-based, nitrile bonded columns as described by Khachik et al (23). Pure forms of each carotenoid were used as reference standards for the quantitation (24). To minimize day-to-day variation, all samples from each subject were run on a single day. The total plasma carotenoid concentration was computed by summing the five specific carotenoids.

Statistical analyses

The data were initially analyzed separately for the effects of multivitamin supplement use, and the season in which the diet and blood data were collected. No statistically significant differences were observed for these effects, and therefore, subsequent analyses were performed on the pooled data of the 98 subjects. In addition, separate analyses were performed on the subset of 66 subjects whose blood samples were collected on similar days of the diet-recording period.

The skewed distributions of weight; body mass index (wt in kg/ht in m²); intakes of total energy, alcohol, and dietary carotenoids; and plasma carotenoid and lipid concentrations were normalized by using log_e-transformations. The geometric means presented are the exponentiated means of the log_e-transformed variables. The arithmetic means, SDs, medians, and ranges of the untransformed variables were also calculated. For variables with 0 values (β -cryptoxanthin intake from the diet records and alcohol intake from both the diet records and FFQ), 1 was added to all the raw values before transformation because the logarithm of 0 is undefined. Although the skewness of these three variables was reduced, they were not normalized despite additional methods of transformation. The results for the transformed data determined by parametric tests were similar to those for the untransformed data determined by nonparametric tests, and thus only the former are presented. All statistical analyses were performed by using the SAS program (25), and two-tailed *P* values < 0.05 were considered statistically significant.

The paired *t* test was used to compare the mean daily carotenoid intakes assessed by the two dietary tools. The intra- and interindividual variabilities of the carotenoid intakes from the diet records, and of the plasma carotenoid concentrations from two blood samples, were estimated by the variance component procedure, *Proc Varcomp* of SAS (25). Pearson product-moment

correlations were computed to examine the interrelationships among the following variables: dietary carotenoid intakes (specific and total) estimated from the diet records and FFQs, specific and total plasma carotenoid concentrations, and several factors including weight and body mass index, intakes of total energy and alcohol, and plasma lipid concentrations. These factors were identified as potential confounders of the diet-plasma carotenoid relationship, as have been previously reported in several studies (9, 10, 26–30). Thus, the diet-plasma carotenoid relationships were adjusted for the confounding effects of these factors by Pearson partial correlations. Similar results were obtained with either weight or body mass index adjustment, and in this report, only the body mass index-adjusted correlations were reported.

Results

Table 2 presents the untransformed means, SDs, medians, and ranges as well as the geometric means for the daily intakes of specific and total carotenoids assessed by the diet records and the FFQs. The mean daily intakes of carotenoids estimated from the FFQ were significantly higher by 10–30% than those estimated from the diet records (Table 3). However, estimates from the two dietary tools for the specific carotenoids and their total were significantly correlated, with the magnitude varying from $r = 0.23$ for lutein to $r = 0.50$ for β -carotene (Table 3).

The untransformed means, SDs, medians, ranges, and geometric means for the average plasma concentrations of the specific and total carotenoids of the two blood samples, collected within 1 wk of each other, are shown in Table 4. Lycopene, lutein, and β -carotene were the major plasma carotenoids, comprising 35%, 28%, and 20% of the total plasma carotenoid concentration, respectively. The plasma carotenoid concentrations of these two blood samples were very highly correlated, ranging from $r = 0.80$ to $r = 0.96$. In addition, very low ratios of intra- to interindividual variabilities were observed for the plasma carotenoids, indicating highly reproducible values (Table 5). Because the plasma carotenoid concentrations from the two blood samples were highly correlated and reproducible, they were averaged for the analyses of this study. In contrast, based on 7 consecutive days of diet records, the ratios of the intra- to interindividual variabilities for all dietary carotenoids were greater than 1 (Table 5). Compared with the other carotenoids, the ratios were highest for lutein and lycopene in both the diet and plasma.

Dietary intakes of the carotenoids, as estimated from the diet records and FFQs, were significantly correlated with their respective plasma concentrations (Table 6). Except for lutein, the correlations were higher when the carotenoid intakes were estimated from the diet records than from the FFQ. These results remained essentially unchanged after adjustment for body mass index, intakes of total energy and alcohol, and total plasma cholesterol concentration. As is further shown in Table 6, the results for the 98 subjects are similar to those observed for the subset of 66 subjects whose plasma carotenoid concentrations were determined from blood samples collected on similar days of the diet-recording period.

Discussion

The dietary intakes of α -carotene, β -carotene, β -cryptoxanthin, lutein, and lycopene, as well as their total intake, were as-

TABLE 6
Correlations between dietary and plasma carotenoids, by dietary-assessment tool¹

Carotenoids	All subjects (n = 98)		Subset (n = 66) ²	
	Unadjusted	Adjusted ³	Unadjusted	Adjusted ³
Diet records				
α-Carotene	0.59	0.58	0.57	0.57
β-Carotene	0.52	0.51	0.52	0.50
β-Cryptoxanthin	0.49	0.49	0.51	0.50
Lutein	0.29	0.31	0.32	0.36
Lycopene	0.41	0.50	0.45	0.54
Total	0.51	0.57	0.56	0.62
Food-frequency questionnaire				
α-Carotene	0.52	0.49	0.53	0.52
β-Carotene	0.44	0.49	0.47	0.50
β-Cryptoxanthin	0.30	0.36	0.24 ⁴	0.31
Lutein	0.29	0.37	0.32	0.37
Lycopene	0.28	0.26	0.33	0.29
Total	0.43	0.49	0.47	0.52

¹ Pearson and Pearson partial correlations were used for unadjusted and adjusted analyses. All Pearson correlations are significant, $P < 0.05$, unless otherwise indicated. Average of two plasma samples, collected within 1 wk of each other, were used.

² Subset whose plasma samples were collected on similar days of the diet-recording period.

³ Adjusted for body mass index, intake of total energy and alcohol, and total plasma cholesterol concentration.

⁴ NS.

essed by two dietary tools in a sample of 98 nonsmoking premenopausal women by using the newly developed USDA-NCI carotenoid food-composition database. The mean daily intakes of these specific carotenoids and their total intake were significantly higher when estimated from the FFQ than from the diet records. The diet-plasma correlations were significant for all carotenoids; however, the magnitudes varied depending on the specific carotenoid and the dietary-assessment tool used.

The varying magnitudes of the diet-plasma correlations for the specific carotenoids may be explained by the differences in their intakes assessed by the two dietary tools. Consistent with reports on several major nutrients (31), including carotenoids (18), significantly higher mean daily intakes of the carotenoids were estimated from the FFQs than from the diet records. These differences may reflect the strengths and limitations of the two tools in assessing nutrient intake (17, 32, 33) as well as the difference in the reference period of food intake. Although estimates from the FFQ, which assessed intake over the past year, may be more representative of the long-term usual intake, its validity may be limited by such factors as over- or underestimation of food intake throughout the questionnaire, errors in the recall of frequency of consumption of certain food items, and inaccuracies in the selection of portion sizes. On the other hand, estimates from the diet records, which represent the current 7-d intake, may not reflect the usual intake. This is shown by the high ratios of intra- to interindividual variabilities of the carotenoid intake, particularly for lutein and lycopene. Thus, possibly because of the high day-to-day variability of carotenoid intake, 7 consecutive days of diet records may not be sufficient for the precise assessment of the usual dietary carotenoid intake (34).

Although the mean daily carotenoid intakes estimated from the FFQ were significantly higher than those estimated from the diet records, intakes from both tools were significantly correlated. This may be attributed to the similar list of food sources of the carotenoids in the two tools. This provides support for the use of

the FFQ to estimate carotenoid intake and to rank subjects by their intake for the examination of the diet-disease relationship in epidemiologic studies. Note, however, that the magnitude of the correlations varied with the specific carotenoid. These findings may reflect the distributions of the specific carotenoids in foods (14, 35), the grouping of the carotenoid and noncarotenoid-rich foods in the same FFQ items, and their differential reporting in the FFQ over the past year relative to the diet records for the 7 consecutive days by this study population. Compared with other carotenoids, β-carotene is more widely distributed in foods, some of which (eg, carrots) are also good sources of α-carotene. This may have accounted for the comparable ranking of their intakes by the two tools. Possibly because β-cryptoxanthin is concentrated in such commonly consumed foods as oranges and orange juice, its intake was ranked fairly similarly by the two tools. The ranking of intake of lutein and lycopene differed most between the two tools, and this may be explained by their distributions in less frequently consumed foods or by their greater day-to-day variability in intake. Thus, the adequacy of using an FFQ to assess carotenoid intake is determined by the correct choice of foods, which reflect the carotenoid sources of the study population, as well as their groupings.

There have been few reports in the literature relating the intakes of specific carotenoids to their respective plasma and serum concentrations. As shown in Table 7, the results of these earlier studies (9, 10, 26–29, 36, 37) are not directly comparable with ours for several reasons: the use of FFQs with different designs for the study of different populations, and the presence or absence of adjustment for different potential confounding factors of the diet-plasma relationships. Furthermore, in these earlier studies the intakes of β-carotene, carotene, and total carotenoid were estimated based on the vitamin A activity of foods (9, 10, 26–29, 37), or for the specific carotenoids, were estimated by using a combination of published and unpublished analytical data (36). These variously defined

TABLE 7
Correlations between dietary and plasma and serum carotenoid concentrations, by study

Reference, smoking status, and sex	Carotenoids		<i>r</i> ¹
	Dietary	Plasma and serum	
Stryker et al (9), nonsmokers			
M/F	Carotene	β -carotene	0.44/0.45
Ascherio et al (10), nonsmokers			
M/F	Carotene	α -Carotene	0.52/0.37
M/F	Carotene	β -Carotene	0.34/0.30
M/F	Carotene	Lycopene	0.13/0.01
M/F	Carotene	Lutein	0.36/0.19
Roidt et al (26), current and former smokers			
M and F	β -Carotene	β -Carotene	0.21 ²
M and F	β -Carotene	α -Carotene	0.25 ²
Willett et al (27), not reported			
M and F	Carotene	Carotenoids	0.35
Bolton-Smith et al. (28), nonsmokers			
M	β -Carotene	β -Carotene	0.28
Russell-Briefel et al (29), smokers and nonsmokers			
M	Carotene	Carotenoids	0.21 ²
M	Carotene	β -Carotene	0.10 ²
M	Carotene	Lycopene	0.08 ²
Coates et al (36), nonsmokers			
F	α -Carotene	α -Carotene	0.38
F	β -Carotene	β -Carotene	0.32
F	Cryptoxanthin	Cryptoxanthin	0.36
F	Lycopene	Lycopene	-0.06
F	Lutein	Lutein/zeaxanthin	0.09
Jacques et al (37), not reported			
M/F	Carotene	Carotenoids	0.19/0.49 ²
M and F	Carotene	Carotenoids	0.37

¹ Adjusted for total energy intake and plasma and serum cholesterol and triglyceride concentrations (9, 10, 27, 28, 36, 37), age (10, 27, 36, 37), body mass index (10, 28, 36), sex (27, 37), alcohol intake (36), and medication and vitamin supplement use (36).

² Unadjusted.

dietary carotenoid indexes were in turn related to the blood concentrations of either total carotenoids (9, 27-30, 37) or specific carotenoids (9, 10, 26, 29). Smoking is another important factor affecting the diet-plasma carotenoid relationship (9, 10, 26, 28, 29, 36). Compared with a group of non-smoking women (36), the adjusted diet-plasma correlations for specific carotenoids were found to be higher in this study. This may have arisen from the use of the specific carotenoid values from the USDA-NCI database, and the more precise relationships of their estimated intakes to the respective plasma concentrations. However, when the same database was used, the correlations between both the FFQ and diet-record estimated specific carotenoids and their plasma concentrations for women in this study were higher than those of men reported by Forman et al (18). This may further be explained by the sex difference in the diet-plasma carotenoid relationship, as was similarly reported by Jacques et al (37).

The results of this study indicated that the diet-plasma correlations for the intakes of α -carotene, β -carotene, β -cryptoxanthin, and lycopene estimated from the diet records were slightly higher than those estimated from the FFQ. Higher correlations between the diet record rather than the FFQ-estimated intake of carotene and plasma β -carotene, were also observed in men by Ascherio et al (10). This finding suggests that blood concentrations of carotenoids may be more reflective of recent than past

intake (38). These findings may have implications in epidemiologic studies in which a single blood concentration of a nutrient, which may not be reflective of the usual dietary-intake pattern, is frequently related to the disease endpoint.

The diet-plasma carotenoid correlations of this study are among some of the highest observed thus far, yet the magnitudes are moderate and varied depending on the specific carotenoid. This may be explained by the varying quality of the specific carotenoid values in the USDA-NCI database, which is highest for β -carotene (13). Furthermore, though these carotenoid values have been critically evaluated for quality and are the median rather than the mean values of varying numbers of food samples, they still may not represent the actual values of the foods consumed by this study population. As noted by Mangels et al (13), the amounts of carotenoids in foods are influenced by such factors as varietal differences, varying growth and harvesting conditions, as well as differences in food-preparation methods, geographic location, and season. However, in the absence of analytical values for the actual foods consumed, the values in the USDA-NCI database are the best available at this time from which intakes can be estimated. In this context, the carotenoid values in the database may be more representative of the actual values of the foods from the FFQ consumed over the longer period of 1 y than for the foods from the diet records consumed over only 7 d. This

may be another reason for the discrepancy in the magnitude of diet-plasma correlations between the two tools.

The ratio of the intra- to interindividual variability in either the circulating or dietary carotenoids is another important factor affecting the magnitude of the diet-plasma carotenoid correlations (34). In this study the carotenoid concentrations determined from plasma samples stored under conditions similar to those used by Craft et al (39) were also found to be highly reproducible over time. Thus, the use of two blood samples with low intra- to interindividual variability may have strengthened the results. However, this may have been offset by the high intraindividual variability of intake of the dietary carotenoids, which could have been ameliorated by additional nonconsecutive days of diet records. In addition, the lower diet-plasma correlations for lutein and lycopene compared with the other carotenoids may be explained by their relatively higher ratios of intra- to interindividual variabilities in both the diet and plasma.

Other than carotenoid intake, the circulating plasma carotenoids may also be influenced by several other dietary and physiological factors. Fat (40) and fiber (41) are among the known dietary factors affecting the bioavailability of carotenoids from the diet. There is limited information on the absorption and metabolism of carotenoids, which have been reported to vary among individuals (42, 43) and to differ among the specific carotenoids (44, 45). Thus, the study of the diet-plasma carotenoid relationships may currently be limited by the existence of unknown potential confounders.

In conclusion, by using the USDA-NCI carotenoid food-composition database, the results of this study have demonstrated that the dietary intakes of specific and total carotenoids, as assessed by diet records and FFQs, were significantly related to their respective plasma concentrations. The magnitude of the diet-plasma correlations varied with the specific carotenoid, and were highest as well as were most comparable for α -carotene, β -carotene, and total carotenoids across the dietary tools. Thus, the use of the FFQ to examine the diet-plasma-disease relationships in epidemiologic studies is reasonably good for α -carotene, β -carotene, and total carotenoids, but may be limited for the other carotenoids. These findings suggest a need for more research on carotenoid metabolism and bioavailabilities from food, as well as the development of a more sensitive dietary tool for the assessment of carotenoid intake. ■

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