The correlation between two dietary assessments of carotenoid intake and plasma carotenoid concentrations: application of a carotenoid food-composition database[1,2]

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ABSTRACT A newly available carotenoid food-composition database providing specific carotenoid values for > 2300 foods was linked to dietary data on 57 male nonsmokers to examine the association between dietary carotenoid intake and plasma carotenoid concentrations over 3 wk when free-living. Carotenoid intake was estimated from a food-frequency questionnaire (FFQ) and 7 d of food diaries with concurrent analysis of plasma carotenoid concentrations. After adjustment for energy intake, percentage of energy from alcohol, and plasma lipid concentrations, significant diet-plasma correlations for the FFQ and the food diaries (FD) included α-carotene (r = 0.29 and 0.43), β-carotene (r = 0.36 FFQ only), β-cryptoxanthin (r = 0.46 and 0.44), lutein (r = 0.44 FD only), and lycopene (r = 0.53 FD only). Dietary carotenoid intakes were associated with plasma carotenoid concentrations for all the carotenoids except for β-carotene when food diaries were used whereas the diet-plasma correlation for the provitamin A carotenoids were consistently significant when the FFQ was used. *Am J Clin Nutr* 1993;58: 519–24.

KEY WORDS Carotenoids, diet, plasma

Introduction

The inverse association between dietary intake of fruits and vegetables and cancer risk has recently been complemented by a similar diet and coronary heart disease relation (1–3). Carotenoid-rich foods have been identified among the fruits and vegetables with potential protective components (1, 4). In the absence of a carotenoid food-composition database, researchers have been unable to identify the specific contribution of carotenoid intake to the diet-disease association.

With growing interest in the role of antioxidant vitamins in the disease process, data on the association between dietary carotenoid intake and plasma carotenoid concentrations contribute to the interpretation of diet-disease relation. Among the studies of the diet-plasma carotenoid associations, biochemical assessment has been limited to one blood collection and dietary assessment has generally relied on a single food-frequency questionnaire, with carotenoid intake based on conversion of vitamin A values to estimate carotene intake (5–9).

A recently developed carotenoid food-composition database provides values for five individual carotenoids in > 2300 foods (10, 11). The carotenoid food-composition database was linked to dietary data from two dietary instruments and correlated with plasma carotenoid concentrations measured at the same times as dietary assessment by using data collected in the free-living state from 57 male nonsmokers. The objectives of this study were to *1*) describe individual and total carotenoid intake by using carotenoid values from the new food-composition database and dietary intake reported on a food-frequency questionnaire and recorded in food diaries for 7 d; *2*) compare the diet-plasma carotenoid correlations based on the food-frequency questionnaire with those based on the food diaries, before and after adjustment for confounding factors; and *3*) describe the number of days of food diaries necessary to reach a diet-plasma carotenoid correlation comparable to the correlation from the week of food diaries.

Methods

Sixty-five men aged 20–40 y were administered two dietary assessment tools in the free-living state: a food-frequency questionnaire followed 1–2 wk later by 7 consecutive days of food diaries. These data-collection activities preceded the controlled diet studies of specific carotenoid-rich foods and pharmaceutical supplements (12–30 mg/d) of β-carotene (12, 13). Volunteers for the controlled diet studies were screened by a medical history, physical exam, and biochemical profile. Among 82 possible subjects, 65 were eligible for the controlled diet studies. All eligible subjects were *1*) within 10% of desirable weight-for-height; *2*) in good health with normal lipid metabolism as indicated by fasting serum cholesterol (2.97–7.11 mmol/L) and triglyceride (0.59–4.09 mmol/L) concentrations and with total plasma carotenoid concentrations 1.3–3.7 mmol/L; *3*) nonsmokers; *4*) not previ-

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ously consuming a vegetarian or other restricted diet; and 5) willing to participate in a controlled diet study of large servings of vegetables (**Table 1**). All procedures were approved by the institutional review boards of the Georgetown University Medical School and the National Cancer Institute. Informed consent was obtained from all subjects in accordance with institutional review board guidelines.

Among 65 eligible subjects, 57 had complete information for the data analysis of the diet-plasma carotenoid relation. Of the eight subjects who were removed, one dropped out; five did not complete or failed a standard computer algorithm for the food-frequency questionnaire, which identified subjects with responses outside the valid range or total frequencies of unusual (too low or high) proportion (14, 15); and two were missing food-diary data.

TABLE 1
Characteristics of the study population at screening*

Subject characteristics	At screening
Age (y)	28 ± 5
Body mass index†	23.4 ± 2
Plasma cholesterol (mmol/L)	3.98 ± 0.80
Plasma HDL cholesterol (mmol/L)	1.11 ± 0.23
Plasma LDL cholesterol (mmol/L)	2.56 ± 0.75

* $\bar{x}$ ± SD; n = 57 men.
† In kg/m^2.

Dietary forms and assessment of carotenoid intake

The carotenoid food-composition database provides values for each of five individual carotenoids in > 2300 fruits and vegetables or multiingredient foods with fruits and vegetables (10, 11). The five individual carotenoids are α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, and lycopene. There are two sections of the carotenoid food-composition database. The first section has carotenoid values from laboratory analyses of individual fruits and vegetables. All data from each laboratory were evaluated by using a computerized system. In this system, several determinants of data quality in each report were examined, ie, analytical method, analytical quality control, number of samples, sample handling, and sampling plan (10). Criteria were established for each determinant of data quality and applied to a decision tree, which led to the acceptance or rejection of the carotenoid values in each report as described by Mangels et al (10). The second section of the food-composition database has carotenoid values for > 2300 fruits and vegetables and multiingredient foods with fruits and vegetables. These carotenoid values represent aggregated values from several carotenoid-rich ingredients in a multiingredient food, the recipe for which came from the Nutrient Data Bank system [Human Nutrition Information Service, US Department of Agriculture (USDA), Hyattsville, MD.] (11).

The Health Habits and History Questionnaire (HHHQ) (14) has a semiquantitative food-frequency questionnaire related to usual eating habits and vitamin and mineral use within the past year. In this study a self-administered version of the HHHQ was provided to each subject at screening. The food-frequency questionnaire listed 100 items in nine sections, with 15 carotenoid-rich items from among 16 items in the fruit section, 19 carotenoid-rich items from among 23 items in the vegetable section, 1 item with tomato-based recipes such as pizza and lasagna, 1 item with tomato-based soups such as minestrone, and 1 item with meat recipes including vegetables, such as beef stew. Each item had one or more individual foods or multiingredient foods, such as green salad.

Several steps were taken to calculate carotenoid intake from the food-frequency questionnaire in the HHHQ. First, for all questionnaire items with more than one food, the frequency of intake of each food was calculated for white males aged 20–40 y on the basis of their 24-h recalls in the 1976–1980 Second National Health and Nutrition Examination Survey (NHANES II) (16) and was weighted to the race and sex-specific US subpopulation. For example, one item listed both tomato and tomato juice, with 22% and 2% of the NHANES II subpopulation consuming each, respectively. Then, the specific carotenoid values for each food in an item were multiplied by this weighted frequency from NHANES II. The product (of the weighted frequency from NHANES II and the individual carotenoid values) was then multiplied by the respondent's actual frequency of intake and portion size to estimate his individual carotenoid intake for each food (15). Finally, the calculated carotenoid intake for each food was summed across individual foods to get the total item-specific carotenoid intake per respondent. Second, for questionnaire items with one food, the food was linked to the carotenoid food-composition database. The respondent's frequency of intake and portion size were multiplied by the individual carotenoid values for the food. Specific carotenoid intake across the items were summed to estimate the respondent's total carotenoid intake from the food-frequency questionnaire.

The estimation of carotenoid intake from the 7-d food diaries was also a multistage process. First, all carotenoid-rich individual foods and multiingredient foods were linked to the carotenoid food-composition database. Second, the individual carotenoid values for each food were multiplied by the actual portion size in grams to estimate the respondent's carotenoid intake per food. Third, individual carotenoid values for all foods were calculated daily and averaged for the week. The total carotenoid intake per day was the sum of all five individual carotenoids. All but one subject kept a food diary (including time, place, food or ingredients, and gram amount) for 7 consecutive days beginning on the same calendar day. The diaries were checked daily by registered dietitians at the US Department of Agriculture Human Studies Facility at Beltsville, MD. The food diaries were analyzed for total energy, fat, protein, and alcohol intakes at the Nutrition Coordinating Center (University of Minnesota, Minneapolis).

Plasma analysis

At screening, on the first diary day, and on the day after completing the diary week, a fasting blood sample was collected in all-plastic syringes (Monvet; Sarstedt, Princeton, NJ) with 4500 units of sodium heparin/L blood. Samples were protected from natural light and centrifuged within 1 h for 20 min at 2260 × g at 12 °C. Aliquot samples of plasma were stored at −70 °C until analyzed. Plasma triglycerides, cholesterol, and high-density-lipoprotein (HDL) cholesterol were analyzed by using a Centrifichem Analyzer (Baker Instruments, Allentown, PA) with standardized procedures and by using Baker reagents (12). Low-density-lipoprotein (LDL) cholesterol was estimated by the formula of Friedewald et al (17).

Individual plasma carotenoid concentrations were determined by the HPLC method of Bieri et al (18) as modified by Craft et al (19). The five major peaks of carotenoids [α-carotene, β-carotene, β-cryptoxanthin, lycopene, and lutein plus zeaxanthin (hereafter referred to as lutein)] plus the sum of all five carotenoid fractions are reported in detail. For all HPLC analyses a laboratory plasma control sample was analyzed daily to verify precision. Crystalline α- and β-carotene, lycopene (Sigma Chemical, St Louis), β-cryptoxanthin, and echinenone (Hoffman La Roche, Nutley, NJ) were used as standards for carotenoid analysis. All samples for each subject were run on a single day to minimize within-day variation.

Data analysis

The data were analyzed in several phases by using the *SAS* software program (20). The analyses were initially stratified by membership in one of two controlled diet studies, but because no differences were observed by study group, the statistical analyses of all subjects were presented. In phase 1 the frequency distribution and measures of central tendency for dietary carotenoid intake and plasma carotenoid concentrations for the five individual carotenoids and the total of the five carotenoids were computed. In addition, the respondent's energy intake based on the HHHQ and his average energy intake during the week recorded in food diaries were compared with his average intake during the (isoenergetic) controlled diet period as a standard. Only one subject had differences between his reported dietary intake and his actual intake over the controlled diet study. Because the results were not appreciably changed with his removal or inclusion, all results presented include data for this subject.

In phase 2 of the data analysis a matrix of Spearman rank correlation coefficients was calculated for (individual and total) dietary carotenoid intake estimated from the HHHQ and from the food diary week, and individual and total plasma carotenoid concentrations at the screening, diary day 1, and the day after the diary week ended. Another matrix included the dietary carotenoid values and potential confounding variables, including body mass index (wt/ht^2); total energy; percentage of energy from alcohol, protein, and fat, (each estimated from the respective dietary tool); dosage of vitamin or mineral supplements; and total plasma cholesterol, plasma HDL cholesterol, and plasma LDL cholesterol concentrations. These factors were previously reported in studies of the diet-plasma carotenoid association (5–9) or in serum lipoprotein transport of individual carotenoids (21). All variables that were statistically significantly associated at a P value ≤ 0.05 were entered into the next phase of the analysis. Although the Pearson product-moment correlations were similar to the Spearman rank correlation coefficients, the Spearman rank correlations are presented because they were less influenced by outlying values and were more robust to meet the normality assumption.

In phase 3 Spearman rank correlation coefficients were computed with adjustment for confounding factors in the form of partial correlations. All correlations were adjusted for energy intake, percentage of energy from alcohol, and plasma LDL cholesterol concentration and, when specified, plasma HDL cholesterol concentrations, and were considered statistically significant at a P value ≤ 0.05.

TABLE 2
Carotenoid intake per day by dietary-assessment instrument*

Carotenoid	HHHQ†	Food diary‡	Correlation§
	μg	*μg*	*r*
α-Carotene	840 ± 621‖	650 ± 567	0.34¶
β-Carotene	3882 ± 2452	3150 ± 2156	0.20
β-Cryptoxanthin	62 ± 59	38 ± 63	0.16
Lycopene	3879 ± 3025	3652 ± 3123	0.36¶
Lutein	2516 ± 1528	2056 ± 2311	0.21
Total	11179 ± 7685	9546 ± 6034	0.22

* n = 57 men.
† Health Habits and History Questionnaire (14).
‡ Average of seven daily food records.
§ Correlation between carotenoid intake calculated from HHHQ and food-diary records.
‖ $\bar{x} \pm$ SD.
¶ $P \leq 0.05$.

TABLE 3
Plasma carotenoid concentrations at screening and for the food-diary week*

Carotenoid	At screening	Diary week	Correlation†
	mmol/L	*mmol/L*	*r*
α-Carotene	0.09 ± 0.07‡	0.07 ± 0.06	0.92§
β-Carotene	0.58 ± 0.3	0.35 ± 0.15	0.89§
β-Cryptoxanthin	0.24 ± 0.16	0.13 ± 0.09	0.91§
Lycopene	1.06 ± 0.41	0.93 ± 0.35	0.78§
Lutein	0.49 ± 0.19	0.42 ± 0.14	0.88§
Total	2.46 ± 0.65	1.90 ± 0.54	0.83§

* n = 57 men.
† Correlation between plasma carotenoid concentrations at screening, on diary day 1, and the day after the diary week ended.
‡ $\bar{x} \pm$ SD.
§ $P \leq 0.0001$.

Results

The individual and total mean carotenoid intake estimated from the HHHQ was consistently higher than the mean intake during the food-diary week (**Table 2**). Estimates of daily dietary carotenoid intake from the HHHQ and from the diary were correlated for α-carotene and lycopene. The individual and total mean plasma carotenoid concentrations were higher at screening than during the food-diary week ≈2 wk later (**Table 3**). The percentage of subjects with a change of one SD or greater from the mean change in plasma carotenoid concentrations over time varied by individual carotenoid. Specifically, 48% of subjects experienced a change of one SD or more in their plasma β-carotene concentrations; 33%, 32%, and 25% experienced this magnitude of change in their plasma β-cryptoxanthin, plasma lycopene, and plasma lutein concentrations, respectively. Not all subjects experienced a decline over time. Fourteen percent of these subjects actually experienced an increase in their (individual or total) plasma carotenoid concentrations after the screening. Finally, all plasma carotenoid concentrations were highly correlated over time.

At screening, daily dietary carotenoid intake estimated from the HHHQ was associated with plasma concentrations of specific

TABLE 4
Correlations between dietary carotenoid intake calculated from the Health Habits and History Questionnaire (HHHQ) and plasma carotenoid concentrations at screening*

Carotenoid	Unadjusted	Adjusted†
α-Carotene	0.25	0.29‡
β-Carotene	0.36§	0.36§
β-Cryptoxanthin	0.33§	0.46§
Lutein	0.11	0.20
Lycopene	0.24	0.26
Total	0.24	0.41§

* n = 57 men.
† All correlations were adjusted for total energy, the percentage of energy from alcohol [based on the HHHQ (14)], plasma LDL-cholesterol concentrations at screening, and plasma HDL cholesterol concentrations were added to the adjustment of the diet-plasma lutein correlation.
‡ $P \leq 0.05$.
§ $P \leq 0.01$.

TABLE 5
Correlations between dietary carotenoid intake calculated from the average of seven food-diary records and the plasma carotenoid concentrations of subjects on the day after the diary week ended*

Carotenoid	Unadjusted	Adjusted†
α-Carotene	0.42‡	0.43†
β-Carotene	0.27§	0.26
β-Cryptoxanthin	0.48‡	0.44‡
Lutein	0.40‡	0.44‡
Lycopene	0.45‡	0.53‡
Total	0.27§	0.35‡

* n = 57 men.
† All correlations were adjusted for total energy, the percentage of energy from alcohol (calculated from food-diary records), and plasma LDL-cholesterol concentrations on the day after the diary week ended; plasma HDL cholesterol concentrations were added to the adjustment of the diet-plasma lutein correlation.
‡ $P \leq 0.01$.
§ $P \leq 0.05$.

provitamin A carotenoids (**Table 4**). Dietary intakes of β-carotene and β-cryptoxanthin were associated with their respective plasma carotenoid concentrations. After adjustment for confounding factors, dietary intakes of α-carotene, β-carotene, β-cryptoxanthin, and total (of all five) carotenoids were associated with plasma concentrations of each individual carotenoid and the sum total of the five carotenoids, respectively.

During the food-diary week, the average daily carotenoid intake and the plasma carotenoid concentrations measured on the day after the week ended had slightly higher correlations than the correlations when plasma concentrations of the carotenoids measured on diary day 1 and the day after the food diary week ended were averaged. **Table 5** has the diet-plasma correlations based on plasma carotenoid concentrations measured on the day after the food-diary week. The average daily intake of each carotenoid during the diary week was associated with its respective plasma carotenoid as well as the total (of all five) carotenoids, ranging from the lowest correlation, that for β-carotene, to the highest, that for β-cryptoxanthin. After adjustment for confounding factors, these correlations changed marginally and remained statistically significant for all carotenoids except β-carotene.

Finally, the number of food-diary days required to reach a diet-plasma correlation of a similar magnitude to the correlation from the recorded week varied by carotenoid (**Table 6**). The daily dietary intakes of lutein and lycopene were associated with their respective plasma carotenoid concentrations when based on 2 d of food-diary records, ie, food-diary days 6 and 7, and this association increased with time. The daily dietary intakes of α-carotene and β-cryptoxanthin were associated with their respective plasma carotenoid concentrations when based on 4 d of food-diary records, ie, food-diary days 4–7, and this association increased with time. Dietary intake of β-carotene and its plasma concentration was not associated throughout the week, with correlations ranging from 0.17 to 0.26.

Discussion

In this paper a newly developed carotenoid food-composition database with values for five individual carotenoids was linked to two dietary tools to estimate carotenoid intake. For each individual and for the total carotenoids, dietary carotenoid estimates were higher when data from the HHHQ was used compared with the food-diary records. The 1–2-mg difference in total carotenoid intake from the two tools was distributed among the carotenoids. The correlations between dietary carotenoid intake from the two tools were significant for α-carotene and lycopene. The list of foods contributing to α-carotene and lycopene intakes, respectively, was similar among the tools, which may have contributed to the degree of correlation.

The higher average daily carotenoid intake assessed with the HHHQ compared with the week of food-diary records was also reflected in the individual and total mean plasma carotenoid concentrations measured at the same times as dietary assessment. The plasma samples were stored for 17–19 mo at −70 °C without thawing before analysis. Under identical conditions in a controlled storage study, there was no significant deterioration in

TABLE 6
Correlations between dietary carotenoid intake calculated from specific food-diary entries and plasma carotenoid concentrations on the day after the diary week ended*

Carotenoid	Day 7	Days 6 + 7	Days 5–7	Days 4–7	Days 3–7
α-Carotene	0.14	0.16	0.26	0.32†	0.38‡
β-Carotene	0.26	0.21	0.17	0.22	0.23
β-Cryptoxanthin	−0.02	0.05	0.22	0.27†	0.37‡
Lutein	0.18	0.31†	0.36‡	0.38‡	0.41‡
Lycopene	0.25	0.34‡	0.33†	0.38‡	0.50‡
Total	0.19	0.25	0.33†	0.31†	0.35‡

* n = 57 men. All correlations were adjusted for total energy, the percentage of energy from alcohol (calculated from food-diary records), and plasma LDL-cholesterol concentrations on the day after the diary week ended; plasma HDL-cholesterol concentrations were added to the adjustment of the diet-plasma lutein correlation.
† $P \leq 0.05$.
‡ $P \leq 0.01$.

carotenoid concentrations for ≤ 28 mo (19). Only seven subjects experienced a decline in all plasma carotenoid concentrations over time. Moreover, among those experiencing a change of ≤ 1 SD from the mean change in plasma carotenoid concentrations, 14% actually had an increase in their plasma carotenoid concentrations from screening to the diary week.

After adjustment for energy intake, percentage of energy from alcohol, and plasma lipid concentrations at screening, dietary intakes of specific and total carotenoids as estimated from the HHHQ food-frequency questionnaire were associated with plasma concentrations of the pro-vitamin A carotenoids and total carotenoids but were not associated with lycopene and lutein. Daily dietary carotenoid intakes, when based on the week of food-diary records, were associated with plasma concentrations of each carotenoid and the sum total except for β-carotene. The range in correlations was slightly higher when dietary data from the food diaries were used than when data from the HHHQ were used; however, the correlation for each individual carotenoid was not consistently higher when food-diary data were used than when HHHQ data were used. Thus, the dietary intake of carotenoids as estimated from two different dietary tools, by using the newly developed carotenoid food composition database, were associated with plasma concentrations of individual carotenoids. Because the correlations were not consistently statistically significant across the tools, use of each tool to estimate the diet-plasma relationship may be dependent on the actual carotenoids of interest.

Any comparisons with earlier research were limited by the use of several semi-quantitative food-frequency questionnaires developed from different populations, with use of different sources for portion-size estimation (5–9), and limited to an estimate of dietary carotene intake, which was calculated from the provitamin A content for each food (22). Compared with the estimate of daily carotenoid intake when the HHHQ was used, the adjusted diet-plasma β-carotene correlation of 0.36 was within the range of reported correlations (0.28–0.48) in earlier studies (5–9). The adjusted diet-plasma correlation for α-carotene (r = 0.29) was lower than the correlations of 0.38 and 0.52 in earlier studies (5, 6); the correlation for lutein (r = 0.29) was higher than one study (r = 0.09) (5), but lower than another study (r = 0.36) (6); the β-cryptoxanthin correlation (r = 0.46) was higher than an earlier one (r = 0.36) (5); and that for lycopene (r = 0.26) was higher than that in earlier studies (r = 0.09–0.13) (5, 6). Therefore, the correlations were within the range of or not much beyond the results of earlier research (5–9).

The adjusted diet-plasma carotenoid correlations derived from the week of food-diary records were compared with an earlier study of two 1-wk periods of diet-record collection over a year among male nonsmokers (6). For our study the adjusted α-carotene correlation of 0.43 was lower than the correlations (r = 0.45 and 0.53) from each week whereas the adjusted β-carotene correlation of 0.26 was lower than (r = 0.40, and 0.50 per week) than those in the earlier study (6). The correlations for lutein (r = 0.44) and for lycopene (r = 0.53) were higher than those from the earlier study (6) (r = 0.28 and 0.36 per week for lutein; and r = 0.06 and 0.13 per week for lycopene, respectively).

The purpose of the food-diary-record analysis was to investigate how many days of food-diary records were sufficient to reach a diet-plasma correlation similar to the correlation for the week. Previous investigators have described a much smaller magnitude of change in plasma carotenoid concentrations from food sources in contrast with pharmaceutical doses in both a single ingestion and long-term diet study, and responses varied by carotenoid (12, 13). The analysis of these food-diary records demonstrated statistically significant diet-plasma correlations for lutein and lycopene with as few as 2 d of food records. These correlations improved considerably with increasing numbers (from 2 to 5 d) of records. At least four diary days were required to reach statistically significant associations for β-cryptoxanthin and α-carotene whereas the diet-plasma β-carotene correlation vacillated within a limited range of values over time. These results indicate a carotenoid-specific lag time between dietary intake and demonstration of a diet-plasma correlation, with lycopene and lutein, two nonprovitamin A carotenoids, requiring the smallest number of diary records to show the correlation. Nonetheless, the correlations after 5 d of records did not reach the values of the correlations in Table 4, which were based on the whole week.

The range in adjusted diet-plasma correlations for individual carotenoids was not much beyond 0.50, as in earlier research. One reason for the similar range might be greater within-subject variability in carotenoid intake and in plasma carotenoid concentrations than in the between-subject variability (23, 24). Single (daily) measurements of plasma carotenoid concentrations have been used in the computation of the diet-plasma correlations (5–9). In this study the ratio of the intra- to interindividual variances in plasma β-carotene concentrations (measured on the 3 blood-collection days) was 0.63 and was similar to a ratio of 0.62 among 24 males participating in an earlier study (25). With this degree of variability, three plasma measurements around each data point would be required to limit attenuation of the diet-plasma correlation to a maximum of 10% (25). Dietary carotenoid intake was based on 7 days of food records, which marked the lower limit of records needed to keep attenuation of the correlation between 10% and 20% in one study (25) and for adequate intake classification in another (26). Thus, even with the use of actual carotenoid values in this study rather than ones calculated from the vitamin A content of specific foods, the number of independent measurements might not have been sufficient to estimate carotenoid intake and measure plasma carotenoid concentrations.

Two other factors that might explain the modest diet-plasma correlations include vagaries in dietary and biochemical assessment and a limited understanding of carotenoid metabolism. Food frequencies have been developed to assess frequency of consumption of foods and assess macronutrient intake but have not necessarily been designed for the assessment of specific micronutrient intake. In this study the HHHQ listed lutein-rich foods in the same questionnaire item as nonlutein-rich foods, eg, cauliflower and brussels sprouts. Because the average lutein intake from an item was calculated from the value for each food, intake of a lutein-rich food in an item would be diluted by the effect of the nonlutein-rich food. A similarly low diet-plasma lutein correlation appeared in another study that used the same dietary tool (5). Moreover, the laboratory procedure did not separate the plasma peak for lutein from that of zeaxanthin (19). Thus, the dietary and biochemical assessment procedures might have contributed to the modest diet-plasma correlations.

Another factor that may have contributed to modest diet-plasma correlations is the limited information regarding the mechanism and regulation of absorption, metabolism, and bioavailability of dietary carotenoids in humans. For example, ca-

rotenoid-rich food sources tend to be high in fiber, but there is little known about the effects of different types of dietary fiber on carotenoid metabolism (27). With limited information, the array of factors influencing the diet-plasma carotenoid relationship may not be taken into consideration in the computation of the correlation.

For the first time, dietary carotenoid intake for the five major carotenoids found in human plasma were compared with their respective values from food sources. The large majority of estimates of dietary intake of specific and total carotenoids were associated with their respective plasma carotenoid concentrations in both dietary tools; yet the correlations were soberingly similar to earlier studies and not much beyond 0.50. Several potential factors might have contributed to the strength of the correlations, including the need for more data points around dietary and biochemical measures, the use of more sensitive tools to assess carotenoid status, and further research in carotenoid metabolism.

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