Racial differences in correlations between reported dietary intakes of carotenoids and their concentration biomarkers[1–3]

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ABSTRACT

Background: The predictive ability of dietary assessment methods to estimate specific circulating plasma carotenoid concentrations has been compared between African Americans and whites in only one study to date.

Objective: The predictive abilities of 24-h dietary recalls and a food-frequency questionnaire in reporting dietary carotenoids when measured against concentration biomarkers were assessed in African Americans and compared with the findings in whites.

Design: Data were collected from 250 generally healthy, nonsmoking white and African American participants aged 21–69 y, who completed 8 self-administered online 24-h dietary recalls and one National Cancer Institute diet-history questionnaire in the University of California Los Angeles (UCLA) Energetics Study. Mean intakes from 4-d dietary recalls were correlated with plasma xanthophyll concentrations (lutein + zeaxanthin and β-cryptoxanthin) and hydrocarbon carotenoids (lycopene, α-carotene, and β-carotene).

Results: Adjusted correlations of plasma carotenoids with reported dietary intakes for African Americans in the 24-h dietary recall ranged from 0.03 for β-carotene to 0.40 for β-cryptoxanthin. For whites, the correlations ranged from 0.13 for lycopene to 0.51 for β-cryptoxanthin.

Conclusions: Despite stronger validity in reported energy intakes for African Americans than for whites in the 24-h dietary recall in the Energetics Study, both recalls and food-frequency dietary assessment methods yielded lower correlations in African Americans than in whites. This finding might be attributable to reporting differences in both dietary sources and food preparation or to racially related genetic variants influencing circulating concentrations. The current findings support the need to account for differences in race, age, sex, and body mass index in regression calibrations of dietary reports and measurement error adjustments. *Am J Clin Nutr* 2011;93:1102–8.

INTRODUCTION

Relations between the intake of carotenoids and the risk of cancers, cardiovascular disease, and stroke are seldom consistent. Results of a recent meta-analysis showed different results with different methods. Case-control epidemiologic studies showed inverse associations between the dietary intake of fruit and/or vegetables and the risk of many cancers, whereas prospective cohort studies showed significant inverse associations only between fruit intake and lung and bladder cancer (1). Furthermore, clinical trials of β-carotene intake and lung cancer have shown only a modest risk reduction with increased intake and no benefits from supplementation (2). Similarly, evidence of a reduction in risk has not been clearly shown in prospective cohort studies or intervention trials, although an association with lower blood pressure has been established (3). Methodologic errors in reporting dietary intake may be precluding accurate estimation of disease risk. These errors are now known to occur with all currently used dietary-assessment methods (24-h dietary recalls, diet histories, and food-frequency questionnaires) (4). In particular, food-frequency questionnaires have been reported to result in an overestimation of the intake of fruit and vegetables (5, 6).

The current focus on improving dietary-assessment methods is through the use of biomarkers to validate and correct errors in the reporting of food consumption, with an emphasis on recovery biomarkers such as doubly labeled water and urinary nitrogen (7). Unfortunately, recovery biomarkers have not been identified for many vitamins and micronutrients. Circulating concentrations of food components, such as carotenoids, act as concentration biomarkers for validating reported intakes (8). We have developed a new Web-based, multipass self-administered 24-h dietary recall method and have examined this tool in generally healthy nonsmoking whites and African Americans (9).

An initial analysis suggests that the collection of multiple-day records of food is feasible (10, 11). A recent publication by Satia et al (8) compared four 24-h dietary recalls with food-frequency questionnaires concerning the reporting of carotenoids intake in a North Carolina population. Herein, we report the ability of our self-administered, Web-based, 24-h dietary recall to predict plasma concentrations of xanthophylls (lutein + zeaxanthin and β-cryptoxanthin) and hydrocarbon carotenoids (lycopene, α-carotene, and β-carotene) in a distinct population of African Americas and whites based in the urban setting of Los Angeles, CA.

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SUBJECTS AND METHODS

Subjects and study design

The University of California Los Angeles (UCLA) Energetics Study was conducted between July 2006 and June 2009. Participants were recruited by using public postings and online advertisements (10). Eligible subjects were generally healthy nonsmoking African American and white adults between the ages of 21 and 69 y who resided within 50 miles (≈80.65 km) of the University of California, Los Angeles. Eligibility requirements included having a stable weight for the previous 6 mo and a willingness to maintain current dietary and physical activity habits for the duration of the study. Subjects also were required to be able to read and speak English, have a working telephone, and be available for all clinic visits and self-administered paper or Web-based questionnaires. Potential subjects were excluded because of any of the following conditions: gastrointestinal surgery; intestinal disease; pancreatic disease; diabetes; hemophilia, alcoholism, mental disorder, hypothyroidism; bipolar or seizure disorders; congestive heart failure, renal failure or other conditions affecting fluid balance; and current treatment with supplemental oxygen, antiretroviral, antineoplastic, antiulcer/antireflux, or central nervous system drugs.

During the consent process, subjects received detailed instructions on how to access and complete the *DietDay* Web-based 24-h dietary recall. Screening and collection of demographic and baseline information was done by using Web-based questionnaires or electronic case report forms, as described previously (10). All subjects completed 2 study visits, eight 24-h dietary recalls, and one food-frequency assessment by using the National Cancer Institute dietary-history questionnaire (NCI-DHQ), as described below. This study was approved by the UCLA Institutional Review Board, and written informed consent was obtained from all subjects.

Dietary assessment

Twenty-four–hour dietary recalls were self-administered by using the Web-based *DietDay* system (http://24hrrecall.com). Details of the method are described in a separate report (10). Briefly, *DietDay* applies multipasses similar to the US Department of Agriculture–designed approach (9). In addition to reported food items, there are multiple levels of questions regarding additional details and ingredients of that food. Complex skip routines allow the subject to be spared certain questions if the food was not reported. *DietDay* contains 9349 foods and >7000 food images; portion sizes are quantified by using food images. Information regarding food-preparation methods, use of condiments, time of day of meal/snack consumption, and consumption of nutritional supplements are also assessed. Nutrient values in the program were based on US Department of Agriculture values with expansion to include mixed dishes and product labeling information. Individual daily intakes of α-carotene, β-carotene, β-cryptoxanthin, lycopene, and the combined intakes of lutein + zeaxanthin were derived from both reported food and supplement use in the recalls and were based on the US Department of Agriculture–Nutrition Coordinating Center Carotenoid Database for US Foods−1998 (http://www.nal.usda.gov/fnic/foodcomp/Data/car98/car98.html).

The first 6 *DietDay* 24-h recalls were conducted over a 2-wk period; the first recall was conducted at the consent visit, another was conducted at each of 2 study visits at the UCLA General Clinical Research Center, and the other 3 were self-administered by subjects via the Internet between the 2 study clinical visits. The final 2 *DietDay* recalls were completed ≈1 and 2 mo after the initial visit. The subjects were notified by automatic E-mail of the need for *DietDay* completion, and nonresponders were pursued by personalized emails and phone calls. Sixty subjects also completed an additional 8 recalls as part of the repeat substudy at 6 mo.

In addition, subjects provided habitual food consumption information for the prior year by using the 36-page, paper-based NCI dietary-history food-frequency questionnaire (NCI-DHQ), which estimates portion sizes and frequencies of consumption of 124 food items and also includes additional queries regarding specifications (eg, fat content and seasonal consumption) for selected foods and supplement use over the past year (4) (http://riskfactor.cancer.gov/DHQ/forms/). The subjects self-administered the NCI-DHQ between the consent visit and the first study visit. Return of the completed NCI-DHQ was required for study entry. Nutrient values assigned to foods recorded in the NCI-DHQ were based on the NCI's nutrient database. The subjects also completed a Web-based general questionnaire, a computer-assisted diet history, a computer administered International Physical Activity Questionnaire, and an exit questionnaire. Results from an evaluation of the computer-assisted diet history and the International Physical Activity Questionnaire will be presented elsewhere.

Plasma nutrients

Blood samples were collected from subjects after a fast of ≥10 h. The samples were protected from light and processed within 1 h of collection at the General Clinical Research Center core laboratory by centrifugation at 2500 rpm for 15 to 20 min. Plasma aliquots (0.5 mL) were stored at −80°C. The samples were analyzed in a batch.

Plasma carotenoids were quantified by HPLC by using a modification of the procedures described by Nomura et al (12). Briefly, after being thawed, 150-μL aliquots of plasma were diluted with 150 μL water and deproteinated by using 300 mL ethanol containing tocol as an internal standard and butylated hydroxytoluene as an antioxidant. The samples were extracted twice with 1 mL hexane, and the combined supernatant fluid was evaporated under nitrogen. The residue was dissolved with vortex-mixing in 35 μL ethyl acetate, diluted with 100 μL of the mobile phase, and ultrasonically agitated for 15 s. A 15-μL volume was injected into the autosampler. The HPLC system autosampler maintained samples at 20°C. The ultraviolet/visible detector was programmed to measure carotenoids at 450 nm. The separation was performed isocratically by using a mobile phase of 80% acetonitrile:15% dioxane:5% of 50/50 methanol/isopropanol containing 150 mmol ammonium acetate/L:0.1% triethylamine at a flow rate of 1.0 mL/min. Total lutein + zeaxanthin was calculated as the total of *trans*-lutein + zeaxanthin and *cis*-lutein + zeaxanthin. Similarly, total β-carotene was calculated as the sum of *trans*- and *cis*-β-carotene.

Statistical analysis

The analyses were performed by using SAS version 9.2 (SAS Institute, Cary, NC). The analysis population comprised 250 of the

262 subjects who completed the study; 12 subjects were excluded because they lacked complete data for one of the variables used in the adjustment of the correlation analysis (*see* below). Descriptive statistics were calculated for demographic and baseline characteristics and plasma and dietary carotenoids. Dietary carotenoid intake was based on the mean of the first 4 *DietDay* 24-h dietary recalls (for direct comparison with other studies) or the NCI-DHQ. The percentage contribution of foods to dietary carotenoids was computed by aggregating food items linked to carotenoid intakes across all 24-h dietary recalls for white and African American participants separately, ranking them in order of increasing reported carotenoid intakes and grouping food items into broader vegetable and fruit categories. Differences between the race groups were determined by using Wilcoxon's tests as a preliminary bivariate analysis, which was followed by multivariate analysis of covariance, where we computed the adjusted means for the carotenoid intake and plasma concentration by race after age, sex, education, body mass index (BMI), and plasma cholesterol were controlled for. Because of the skewed distributions of the dependent variables, log transformations were used. The resulting residuals after log transformation were normally distributed and homoskedastic; therefore, we used log transformation with the appropriate retransformation to arrive at the adjusted results. Pearson correlation analyses were based on natural log-transformed data and were adjusted for age, education, sex, race, BMI, and plasma cholesterol. In the case of zero values for a dietary carotenoid, half of the lowest intake value for that carotenoid was imputed. Natural logarithmic transformation was used to improve the normal distribution of plasma and dietary carotenoids. However, the distribution of plasma lycopene was found to be closer to normal before transformation; thus, correlations for lycopene were based on nontransformed plasma values. Differences between correlations for the 2 race groups were examined by using Fisher's z transformation.

RESULTS

Demographic characteristics

Of 333 individuals who provided consent, 268 were enrolled and 262 (98%) completed the study. Half of the subjects who completed the study were white and half were African American. As shown in **Table 1**, demographic characteristics differed somewhat between the race groups. Greater than half of the subjects in both race groups were women, and whites were somewhat younger. African Americans were more likely to be overweight than were whites in this cohort: 37.1% of African Americans and 51.6% of whites reported being college graduates.

Dietary and plasma carotenoids

Differences in supplement use were reported between whites and African Americans: 45.2% of the whites and 32.6% of the African Americans (χ^2 = 6.6, df = 2, P = 0.01) reported using multivitamins. In addition, 5.0% of whites and 4.7% of African Americans used antioxidant or carotenoid supplements (χ^2 = 0.02, df = 2, P = 0.88). Despite the fact that carotenoid intakes were added to the reported food intakes with the recalls, reported dietary intakes of all carotenoids were markedly higher when subjects used the NCI-DHQ than when they used *DietDay* as the assessment tool. This finding is similar to that reported by Satia et al (8) when they applied both methods to a population of whites and African Americans living in North Carolina. Their median intakes by assessment method and race can be found in **Table 2**.

TABLE 1
Demographic and baseline characteristics of subjects in the University of California Los Angeles (UCLA) Energetics Study

	All subjects (n = 250)	African Americans (n = 124)	Whites (n = 126)	P values
Sex (%)				
Female	65.2	70.2	60.3	0.09
Male	34.8	29.8	39.7	
Age (y)	37.7 ± 12.7[1]	39.4 ± 11.8	36.1 ± 13.3	0.04
Age (%)				
21–29.9 y	40.0	26.6	53.2	<0.001
30–49.9 y	37.6	50.8	24.6	<0.001
50–69 y	22.4	22.6	22.2	0.88
BMI (kg/m^2)	26.6 ± 6.1	28.6 ± 6.6	24.6 ± 4.8	<0.001
BMI (%)				
<18.5 kg/m^2	3.20	2.4	4.0	0.41
18.5–24.9 kg/m^2	45.2	29.0	61.1	0.04
25–29.9 kg/m^2	28.8	34.7	23.0	<0.001
≥30 kg/m^2	22.8	33.9	11.9	<0.001
Education (%)				
<High school graduate	2.8	5.6	0	0.01
Some college	37.6	50.0	25.4	<0.001
College graduate	44.4	37.1	51.6	0.02
Postgraduate	15.2	7.3	23.0	<0.001
Serum cholesterol (mg/dL)	172.7 ± 39.3	177.5 ± 38.5	167.9 ± 39.7	0.03
Total energy expenditure (kcal/d)[2]	2445 (2375, 2517)	2384 (2088, 2874)	2448 (2341, 2559)	0.11

[1] Mean ± SD (all such values).
[2] Total sample, n = 233; African Americans, n = 118; and whites, n = 115. Values are geometric means (95% CI) for total energy expenditure.

TABLE 2
Dietary carotenoids in African Americans and whites in the University of California Los Angeles (UCLA) Energetics Study[1]

	African Americans (n = 124)				Whites (n = 126)				
Carotenoid	Geometric mean	Median (95% CI)	Median, Satia et al (8)	Adjusted means[2]	Geometric mean	Median (95% CI)	Median, Satia et al (8)	Adjusted means[2]	P value[3]
DietDay (four 24-h recalls)[4]									
Xanthophylls (μg/d)									
Lutein + zeaxanthin	3420	3261 (1610, 6680)	1631	3090	4500	3460 (1870, 11,140)	2411	3210	NS
β-Cryptoxanthin	110	104 (5, 340)	140	99	120	132 (50, 250)	164	112	NS
Hydrocarbons (μg/d)									
Lycopene	3170	4843 (1960, 11,304)	3241	4723	6320	8724 (323, 15,630)	4890	6475	0.002
α-Carotene[5]	310	334 (100, 1360)	175	286	71	1102 (26, 1850)	305	987	0.001
β-Carotene[5]	1420	1529 (794, 3797)	2151	1298	2027	2108 (978, 4102)	2937	1926	0.050
NCI-DHQ[6]									
Xanthophylls (μg/d)									
Lutein + zeaxanthin	2316	1988 (1203, 4207)	1936	2114	2606	2523 (1517, 4544)	3034	2186	NS
β-Cryptoxanthin	152	160 (83, 279)	125	118	132	152(89, 221)	194	115	NS
Hydrocarbons (μg/d)									
Lycopene	4924	4363 (2551, 8812)	3970	5762	5659	6152 (3219, 9040)	4343	5885	NS
α-Carotene	406	359 (206, 847)	242	456	557	564 (252, 1189)	617	546	0.05
β-Carotene	2610	2299 (1332, 5577)	2865	2237	3152	3219 (1897, 5363)	3625	3246	0.04

[1] NCI-DHQ, National Cancer Institute diet-history questionnaire.
[2] Adjusted by age, sex, education, BMI, and total plasma cholesterol.
[3] P values for adjusted means estimated by ANCOVA.
[4] *DietDay* (http://24hrrecall.com)–estimated mean energy intake was 2174 kcal/d for African Americans and 2086 kcal/d for whites.
[5] The cited article from Satia et al (8) listed dietary α-carotene values twice in Table 1. We assumed that the higher values referred to β-carotene and the lower values to α-carotene.
[6] NCI-DHQ–estimated mean energy intake was 1783 kcal/d for African Americans and 1782 kcal/d for whites.

Reported dietary intakes of lutein + zeaxanthin and β-cryptoxanthin, reported using both dietary-assessment methods, were similar between the race groups, whereas intake of the other 3 carotenoids differed between the races according to one or both of the assessment methods (Table 2). White subjects reported significantly higher intakes of β-carotene and α-carotene than did African Americans with both dietary-assessment instruments. Reported lycopene intake was significantly higher in whites according to the *DietDay* assessment (8724 compared with 4843 μg/d; P = 0.002), but not by the NCI-DHQ.

Plasma concentrations of lutein + zeaxanthin, β-cryptoxanthin, and lycopene were similar between the 2 race groups, whereas both α- and β-carotene concentrations in plasma were higher in whites than in African Americans (**Table 3**). This racial difference in plasma carotenoids was also found in the National Health and Nutrition Examination Survey as reported by the Centers for Disease Control and Prevention (13). Overall, as might be expected in a population of healthy Californian adults, plasma concentrations of most carotenoids were higher than those in the nationally representative sample for both racial groups.

Correlations between dietary intake and plasma carotenoids

Pearson correlation coefficients between carotenoid intake, as assessed by either *DietDay* or the NCI-DHQ, and the respective plasma carotenoid concentration biomarker for each race group are shown in **Table 4**. In whites, each of the carotenoid intake amounts reported by using *DietDay* was significantly correlated with its respective concentration biomarker, and the highest correlations were observed for β-carotene, lutein + zeaxanthin, and β-cryptoxanthin. In contrast, in African Americans, only β-cryptoxanthin showed a correlation as high as 0.40 between intake reported by *DietDay* and the biomarker.

Correlations in whites between intake reported with the NCI-DHQ and all carotenoid biomarkers, except β-cryptoxanthin and lycopene, were similar to those observed with *DietDay*. In African Americans, with the exception of β-cryptoxanthin, correlations between intake reported by the NCI-DHQ and carotenoid biomarkers were stronger than those observed for *DietDay* and biomarkers. When compared by race group, correlations between plasma and β-carotene reported with either dietary-assessment method and between plasma and *DietDay*-reported lutein + zeaxanthin were significantly higher for whites than for African Americans. The greatest discrepancy was in β-carotene correlations, which measured 0.38 in whites and only 0.03 in African Americans.

Foods contributing to carotenoid intake

Foods that contributed the largest proportion of each carotenoid, as assessed with *DietDay*, in African American and white subjects are shown in **Table 5**. Items that contributed the most lutein + zeaxanthin were spinach and other greens (combined sum: African Americans, 64.7%; whites, 68.7%) and oranges and tangerines for β-cryptoxanthin (combined sum: African Americans, 72.8%; whites, 76%). Heat-processed tomatoes and raw tomatoes (combined sum) contributed the high amounts of lycopene in both

TABLE 3
Plasma carotenoid concentrations (in μmol/L) of subjects in the University of California Los Angeles (UCLA) Energetics Study[1]

	African Americans (n = 124)					Whites (n = 126)					
Carotenoid	Geometric mean	Median (95% CI)	Adjusted means[2]	Geometric mean, CDC (13)[3]	Median (95% CI), CDC (13)[3]	Geometric mean	Median (95% CI)	Adjusted means[2]	Geometric mean, CDC (13)[3]	Median (95% CI), CDC (13)[3]	P value[4]
Xanthophylls											
Lutein + zeaxanthin	0.25	0.25 (0.20, 0.33)	0.22	0.25	0.25 (0.23, 0.27)	0.27	0.27 (0.20, 0.38)	0.24	0.22	0.22 (0.20, 0.23)	NS
β-Cryptoxanthin	0.18	0.18 (0.12, 0.26)	0.16	0.15	0.14 (0.13, 0.15)	0.16	0.16 (0.11, 0.24)	0.14	0.12	0.12 (0.11, 0.13)	NS
Hydrocarbons											
Lycopene	0.60	0.64 (0.50, 0.80)	0.61	0.40	0.44 (0.41, 0.45)	0.57	0.62 (0.44, 0.79)	0.59	0.39	0.41 (0.39, 0.43)	NS
α-Carotene	0.06	0.05 (0.03. 0.10)	0.04	0.03	0.03 (0.02, 0.04)	0.08	0.08 (0.05, 0.12)	0.07	0.05	0.04 (0.04, 0.05)	0.001
β-Carotene	0.28	0.26 (0.16, 0.51)	0.23	0.20	0.20 (0.19, 0.21)	0.33	0.33 (0.22, 0.52)	0.31	0.23	0.23 (0.22, 0.52)	0.05

[1] CDC, Centers for Disease Control and Prevention.
[2] Adjusted by age, sex, education, BMI, and total plasma cholesterol.
[3] CDC values were collected from subjects aged ≥3 y and were converted to match the units used in this study (ie, μg/dL converted to μmol/L).
[4] P values for comparison by race of adjusted means estimated by ANCOVA.

race groups (African Americans, 63.0%; whites, 69.2%). However, tomato/vegetable juice contributed 15.5% of the daily lycopene in whites, and watermelon contributed 28.6% of lycopene in African American subjects. Notably, the largest contributors to β-carotene intake in both races were carrots and spinach (African Americans, 28.1%; whites, 43.8%); African Americans also derived 9.2% of their β-carotene intake from mixed fruit smoothies.

DISCUSSION

The current study examined correlations between dietary intake of carotenoids and their associated plasma concentration biomarkers in African American and white subjects living in the urban setting of Los Angeles, California. Among whites, we observed significant correlations between diet and biomarkers for all carotenoids when *DietDay* was used for dietary assessment. Similarly, when the NCI-DHQ was used for dietary assessment in whites, all carotenoids examined, except lycopene, showed significant correlations between diet and plasma. In contrast, in African Americans, poor correlations for dietary and plasma carotenoids were observed when *DietDay* was used, and, although better with the NCI-DHQ than with *DietDay*, the correlations were still weaker than those observed in whites (14). This finding adds to that of other studies showing higher correlations of dietary and plasma biomarkers in whites than in African Americans (15, 16).

The difference in correlations was unlikely to be due to differences in the overall reporting of diet with the recall method. In fact, when total energy expenditure was calculated from doubly labeled water and validated against multiple 24-h-recalls, *DietDay* performed equally well if not better in African Americans than in whites (14). Despite the stronger validity in reported energy intakes in African Americans than in whites with this 24-h recall,

TABLE 4
Pearson correlations between reported dietary intakes and corresponding plasma carotenoids of subjects in the University of California Los Angeles (UCLA) Energetics Study[1]

	DietDay (four 24-h recalls)[3]			NCI-DHQ		
Carotenoid[2]	African Americans	Whites	P for between-group comparison	African Americans	Whites	P for between-group comparison
Xanthophylls						
Lutein + zeaxanthin	0.23	0.48	<0.001	0.21	0.47	0.004
β-Cryptoxanthin	0.40	0.51	<0.001	0.26	0.33	NS
Hydrocarbons						
Lycopene	0.15	0.13	NS	0.20	0.002	NS
α-Carotene	0.18	0.27	<0.001	0.24	0.28	NS
β-Carotene	0.03	0.38	<0.05	0.17	0.31	0.004

[1] NCI-DHQ, National Cancer Institute diet-history questionnaire. All correlations were adjusted for age, sex, education, BMI, and total plasma cholesterol and were log transformed.
[2] For lycopene and α-carotene, dietary intakes of 0 μg/d were replaced with 50% of the lowest dietary intake averaged over the first 4 d. For these 2 carotenoids, the values were 0.14 and 0.072 μg/d, respectively. This was not necessary for the other carotenoids because the reported dietary intakes averaged over the first 4 *DietDay* days were >0 μg/d.
[3] *DietDay* (http://24hrrecall.com).

TABLE 5
Major food contributors to dietary intakes of carotenoids in the University of California Los Angeles (UCLA) Energetics Study[1]

Food	Whites	African Americans
Lutein + zeaxanthin (%)		
Spinach	51.1	42.6
Greens	17.6	22.1
Broccoli	4.2	6.1
Beans	3.5	3.3
Salad greens	3.4	2.6
Lycopene (%)		
Heat-processed tomatoes	38.4	40.6
Raw tomatoes	31.8	22.4
Vegetable juice	15.5	—
Watermelon	9.8	28.6
Grapefruit	3.3	4.5
Meatball/sausage subs	—	2.4
β-Cryptoxanthin (%)		
Oranges	57.4	60.3
Tangerines	18.6	12.5
Watermelon	—	9.4
Papayas	4.8	3.9
Peaches	3.5	—
Apples	5.4	3.8
β-Carotene (%)		
Carrots	22.4	13.2
Spinach	21.4	14.9
Sweet potatoes/yams	5.9	—
Prepared smoothies	—	9.2
Cantaloupe	5.3	9.7
Tossed salads	2.7	4.8

[1] Only the top 5 foods (by % contribution) are shown for each carotenoid.

DietDay yielded lower adjusted correlations between dietary intakes and plasma carotenoids in African Americans than in whites. The difference in the level of correlation between racial groups was significant by *z* transformation for lutein + zeaxanthin (both *DietDay* with biomarker and DHQ with biomarker) and for β-carotene (*DietDay* with biomarker).

These findings indicate that whereas both dietary-assessment methods appear to be valid for carotenoid intake by the respective biomarker in whites, both methods appear to be less valid in the African American population. Genetics, consumption of foods with different bioavailabilities, and subjective differences in responses to dietary-assessment tools each may contribute to racial differences in diet-disease relations.

A recent study of genetic influences on β-carotene absorption (17) suggests that the poor correlations between dietary intake and plasma values may be due to a common genetic variation that affects circulating concentrations. The *G* allele at rs6564851 near the *BCMO1* gene is associated with higher circulating α- and β-carotene and lower lycopene and lutein + zeaxanthin concentrations. As reported by Ferrucci et al (17), the variant, which reduces the conversion of β-carotene to vitamin A (18), has a prevalence of ≈50% in Europe, 30% in China, 25% in Japan, and 0% in Nigeria and is apparently practically nonexistent in Africa (17). Thus, there is a biological basis to expect differences in the strength of correlations.

In addition, the possibility that the online 24-h recall does not capture dietary intakes as accurately in African Americans as it does in whites deserves attention. This was not likely to be due to differences in response to the dietary-assessment method in general, because energy validation in the African Americans was as good as that in whites and it stabilized more rapidly with fewer days in African Americans than in whites. Furthermore, because the differences between the 2 racial groups were also observed with the food-frequency questionnaire, we suspect that other factors account for these discrepancies.

The third difference may be in the bioavailability and stability of the biomarker. Smoking is known to affect circulating carotenoid concentrations (19). However, for this reason, individuals admitting to be smokers were excluded from the study. Correlation analyses were adjusted for age, sex, education, BMI, and total plasma cholesterol to control for these possible confounders. Carotenoid bioavailability still may differ between these subpopulations, depending on which food sources were consumed and which preparation methods were applied. The low correlations for the hydrocarbon carotenoids in the African Americans are of particular interest, because intakes of β-carotene, α-carotene, and lycopene reported by both *DietDay* and the NCI-DHQ were higher in whites than in African Americans. Circulating concentrations and the bioavailability of micronutrients may be influenced by metabolism, total energy intake, plasma lipid concentrations, lifestyle factors, food-food and food-drug interactions, and cooking methods (20, 21). Therefore, correlations between dietary carotenoid intakes and concentration biomarkers are subject to variability, depending on the bioavailability of the carotenoid and within-person variability (13). In the current study, plasma concentrations reflected a single point in time and could not be adjusted for intraindividual differences in bioavailability. The low correlation values observed for lycopene in both groups and with both dietary-assessment instruments could be attributed to the limited bioavailability of *all-trans* lycopene—the primary isomer concentrated in lycopene-rich foods. Of note, the major source of lycopene in all subjects was heat-processed tomatoes—a source that should provide better bioavailability because the heating and canning process increases the release of lycopene from the plant matrix and might also aid in the in vivo isomerization of the *all-trans*-isomer to the *cis*-isomer, which is preferentially absorbed and is the major form in the plasma (22).

Many previous and recent studies have correlated dietary intakes with circulating carotenoids, but no clear pattern has emerged. The 24-h dietary recalls in the study by Talegawkar et al (23) were administered ≈1 mo apart, within a 6-mo time frame, which suggests that longer-term consumption of lycopene may correlate better with circulating plasma concentrations. In contrast with the current results, Satia et al (8) observed distinct differences between racial groups, with African American subjects having higher correlations between the 24-h recall and biomarker for β-cryptoxanthin, lutein + zeaxanthin, and lycopene than did whites. These differences may be attributable to differences in carotenoid intakes in the different African American population studies. Overall, whereas the pattern of foods contributing the highest proportions of each carotenoid was relatively similar, the consumption of cooked greens was a major contributor to intake of β-carotene and lutein + zeaxanthin in the African American southern population, but not in the urban Western African American population (8, 20). Moreover, the total median reported intake of each carotenoid, by either 24-h recall or food-frequency questionnaire, was markedly higher in the southern African

American population than in either race group in the current study (23). Thus, geographic dietary differences between populations, and racial differences, may alter the strength of the dietary-assessment tools.

The effect of bias in dietary intake reporting is of great interest in current nutritional epidemiologic research. Bias might lead to over- or underreports of fruit and vegetables consumption, which results in a skewed estimation of true associations. As has been reported by others for fruit and vegetable consumption, we observed substantially higher median reported intakes of all carotenoids when subjects used the NCI-DHQ than when they used *DietDay*. Because the DHQ estimates yearly intake, the most recent findings indicate overestimation of foods regarded as "healthy" with food-frequency questionnaires, whereas multiple 24-h dietary recalls more accurately reflect actual fruit and vegetable intakes. Despite these stark differences in reported dietary carotenoid intakes, the *DietDay* method still outperformed the NCI-DHQ method overall in whites. In African Americans, the 24-h dietary recalls performed as equally well as the food-frequency questionnaire for xanthophyll carotenoids. However, for the hydrocarbons, the DHQ may be preferred for assessing carotenoid concentrations in African Americans. These findings support the need to account for differences in race, age, sex, and BMI in regression calibration of dietary reports and measurement error adjustments.

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