Validation of Three Food Frequency Questionnaires and 24-Hour Recalls with Serum Carotenoid Levels in a Sample of African-American Adults

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Abstract:

The validity of self-reported fruit and vegetable intake in minority populations has not been adequately established. In this study, the authors examined the association of three food frequency questionnaires (FFQs) and 24-hour dietary recalls with serum carotenoid levels. Approximately 1,000 African-American adults recruited from 15 churches in Atlanta, Georgia (1997–1998) completed three fruit and vegetable FFQs: a seven-item instrument assessing intake during the past month; a two-item measure assessing usual intake; and a 36-item measure adapted from the Health Habits and History Questionnaire. A total of 414 participants received a 24-hour recall by telephone, and 105 of them received two additional recalls. Serum levels of lycopene, lutein, cryptoxanthin, α-carotene, and ß-carotene were assessed in 813 participants and used as the validity criterion. The correlations of fruit and vegetable servings with specific and total serum carotenoid levels were generally higher for the 36-item FFQ than for the two-item and seven-item instruments. The strongest correlation of fruit and vegetable servings with total carotenoid levels was observed for the three recalls ($r = 0.42$), with the 36-item FFQ and the single 24-hour recall yielding comparable correlations ($r = 0.35$ and $r = 0.37$, respectively). The validity of the 36-item fruit and vegetable FFQ was generally as strong as the validity of both 1 and 3 days of recalls. Given the lower cost and time needed for administration relative to recalls, it appears that the 36-item FFQ has merit for evaluating fruit and vegetable health interventions.
antioxidants; biological markers; carotenoids; diet surveys; fruits; questionnaires; recall; vegetables
Abbreviations: FFQ, food frequency questionnaire; HHHQ, Health Habits and History Questionnaire.

Article:

INTRODUCTION

A diet rich in fruits and vegetables conveys considerable health benefits, including reduced risks of several cancers, heart disease, and stroke (1–6). Increasing Americans' consumption of fruits and vegetables is a national health priority (7, 8), and numerous health interventions designed to increase fruit and vegetable intake have been developed (7, 9–11). However, the question of how best to assess fruit and vegetable intake has not been entirely resolved.

When evaluating health interventions promoting fruit and vegetable consumption, investigators have typically employed 24-hour recalls, prospective food diaries, or food frequency questionnaires (FFQs), often using multiple methods. Each assessment approach has advantages and disadvantages that must be weighed in selecting the method (or methods) which best meets the needs of a particular evaluation (12-14). The advantages of 24-hour recalls include precision and, when multiple days are assessed, validity. Disadvantages include cost and administration time; the need to obtain multiple recalls to reliably estimate usual intake; participant burden; and literacy demands in the estimation of portion size (12). The advantages of diaries are similar to those of recalls, with the added disadvantage of increased literacy demands and respondent burden. Advantages of FFQs include relatively lower administrative costs and time and the ability to assess usual and longer term intake; disadvantages include inaccuracy of absolute nutrient values, fluctuation of nutrient values depending on instrument length and structure (15), lack of detail regarding specific foods, and general imprecision (12, 16).

One factor in choosing an evaluation method is validity. One type of validity, criterion validity, involves the comparison of values from one instrument with a "gold standard" measure of known validity. In the case of dietary assessment, there is debate about whether such a gold standard exists (16, 17). With the possible exception of extensive diet diaries (e.g., 14–21 days in length) or direct behavioral observation, most assessment methods convey considerable error and are subject to several forms of bias. In the absence of a gold standard, another method for determining the validity of a dietary assessment measure is comparison with a nutritional biomarker. Whereas data from the various types of self-report dietary assessment methods may be correlated because of common sources of error, serum biomarkers are assumed to be independent of respondent bias, and therefore they represent a useful means of determining the validity of self-reported dietary behavior. Determining the threshold of acceptable validity coefficients between self-reported diet and biomarkers is often difficult (i.e., deciding how large a correlation is required to establish validity), since most biologic measures of nutrients/metabolites are influenced by factors other than food intake (e.g., metabolic rate, age, tobacco and alcohol use, vitamin supplementation). However, when comparing multiple methods of dietary assessment with a biomarker, determination of validity can be based on the relative magnitude of association across instruments rather than absolute magnitude.

FFQs (18–27) and diet recalls/diaries (28, 29) have, in separate studies, been validated against serum carotenoid levels. However, only a handful of studies have examined relative validity between multiple assessment methods (30–34). In most multimethod comparisons, the correlation between dietary carotenoids and serum carotenoids was generally higher for diary methods than for FFQs, whereas correlations for FFQs and dietary recalls (ranging from 1 day to 12 days) have not shown consistent differences (30–32, 34–36). There has been little validity research on methods of assessing fruit and vegetable intake or general diet among African

Americans (19, 37), and we could identify no published studies in African Americans that compared multiple methods with a biomarker.

In this study, we examined the association of four methods of assessing fruit and vegetable intake (three FFQs of varying length and format, as well as 24-hour recalls) with serum carotenoid levels in a sample of African-American adults (38). Results address both the absolute magnitude of the associations and the relative associations between methods.

MATERIALS AND METHODS

Data for this analysis were derived from the baseline assessment of the Eat for Life Trial, a federally funded intervention designed to increase fruit and vegetable intake among African-American adults in Atlanta, Georgia (38). Participants were recruited through Black churches in the Atlanta metropolitan area between August 1997 and April 1998. Prior to randomization, churches were matched according to socio-economic status (low, mixed, or high) and size. They were then assigned to one of three treatment conditions: 1) comparison (usual nutrition education); 2) culturally sensitive multicomponent intervention with one telephone counseling call; and 3) culturally sensitive multicomponent intervention with four telephone counseling calls. The telephone counseling in the two intervention groups was based on Motivational Interviewing, a technique originally developed for addiction treatment that has potential application to other health behaviors (38–40). Four churches were assigned to each of conditions 1 and 3, and six were assigned to condition 2. In addition to the 14 churches from the intervention trial, data from one church that served as the pilot site were also included in the current analyses, because the assessment methods used therein were identical to those in the full trial. All assessments were made prior to initiation of the intervention. Additional information regarding the study can be found elsewhere (38).

Measures

FFQs.

Three FFQs of varying length and format were administered. Participants completed a seven-item fruit and vegetable FFQ assessing intake in the past month, based on the Behavioral Risk Factor Surveillance System instrument (41). To limit overreporting, we removed the response categories of four and five times per day. The second FFQ was a two-item measure that asked about the number of servings of fruit and the number of servings of vegetables usually consumed each day. The third FFQ was a 36-item measure of fruit and vegetable intake developed for this study that was based on the Health Habits and History Questionnaire (HHHQ), version 2.1 (42). To improve the validity of the instrument, we made several modifications to the original HHHQ. First, participants were asked to indicate the number of times they had consumed each item in the past week, as opposed to the longer retrospective time frame typically employed (43). Second, respondents indicated frequency of consumption using an open-ended rather than a closed-ended format. Third, portion size for each fruit and vegetable was included in the question (e.g., one whole apple). Portion size was fixed at a medium serving. Finally, several items that were paired in the original HHHQ (e.g., tomatoes and tomato juice) were separated into individual items. The three FFQs assessed only fruit and vegetable intake, the primary outcome for the intervention trial.

Dietary carotenoid levels were estimated from the 36-item fruit and vegetable FFQ. For each question on the 36-item FFQ, values for the five major carotenoids (lycopene, lutein, cryptoxanthin, α-carotene, and ß-carotene) were obtained from the US Department of Agriculture–Nutrition Coordinating Center (University of Minnesota) carotenoid database (44); if values were not available in this database, they were obtained from other sources (45. Carotenoid databases provide values per 100 grams. We therefore converted a medium portion size of each fruit and vegetable to 100-g equivalents prior to computing carotenoid levels, using a national database (46).

Several questions on the 36-item FFQ asked about multiple foods–for example, "How often do you eat apricots, pears, or plums?" To generate a single carotenoid value for multiple-food questions, we developed a separate "calibration" questionnaire that separated each food into single items. Additionally, for some foods, such as "green salad," carotenoid values differed substantially depending on the specific food source (e.g., iceberg lettuce vs. romaine lettuce). Therefore, the calibration questionnaire also solicited details on how often specific types of foods were consumed (e.g., iceberg lettuce vs. romaine lettuce, pink grapefruit vs. white grapefruit, and raw cabbage vs. cooked cabbage). This instrument was administered to 114 African-American adults recruited through local Black churches who were not participating in the larger trial. Their responses were used to weight each item for computation of values for the multiple-food items in the 36-item FFQ, as well as to determine which food source or preparation method should be used in computing carotenoid levels. For example, if apricots were eaten twice as frequently as plums or pears, the carotenoid values for apricots would be weighted twice as much as those for pears or plums when we computed levels for that questionnaire item. Similar weighting factors were generated for food type (canned vs. fresh) and preparation method. We reviewed data from approximately 100 of the 400 24-hour recalls to obtain additional information for the weighting. We excluded from the analysis any participant who was missing information on more than half of the vegetable items (i.e, 10 items) or fruit items (i.e., eight items) from the 36-item FFQ. Cases with missing data on fewer than half of the fruit or vegetable items were assigned a frequency of "never" for those items.

24-hour recalls.
Approximately 40 percent of the sample (n = 414) was administered a single 24-hour recall by telephone, using the Minnesota Nutrient Data System (food database, version 12A, and nutrient database, 1999 revision; Nutrition Coordinating Center, University of Minnesota, Minneapolis, Minnesota). Participants were randomly selected from the roster of all participants until 414 recalls had been completed. Of these 414 participants, 105 (25 percent) were randomly selected to receive two additional recalls. To obtain the 414 single recalls, we approached 618 participants (response rate = 67 percent). For the triplicate recalls, we approached 226 individuals, 105 of whom participated (response rate = 46 percent).

Recalls were conducted by the Diet Assessment Center of Pennsylvania State University (University Park, Pennsylvania) using a multiple pass approach. A two-dimensional food portion poster (Nutrition Consulting Enterprises, Framingham, Massachusetts) was mailed to participants prior to interviews to provide assistance in portion size estimation. The Diet Assessment Center used output files generated by the Nutrient Data System to analyze intakes of fruits and vegetables. A master food group file containing all Nutrient Data System food identifiers,

descriptions, and fruit and vegetable assignments was created for merging with individual food intake data. Fruit and vegetable group assignments were based on the National Cancer Institute's 5-A-Day definitions (7). Certain fruits and vegetables such as ketchup, French-fried potatoes, olives, and avocados were excluded from the calculations. Fruits and vegetables contained in mixed dishes were generally counted in the fruit and vegetable computation. Total daily carotenoid levels (lycopene, lutein, cryptoxanthin, α-carotene, and ß-carotene) were computed using the US Department of Agriculture–Nutrition Coordinating Center database. Carotenoid values from the 24-hour recalls were based on all foods consumed, not only fruits and vegetables. Intraclass correlation coefficients for the 3 days of recalls were 0.62 for fruit and vegetable servings, 0.00 for lycopene, 0.56 for lutein, 0.52 for cryptoxanthin, 0.17 for α-carotene, and 0.47 for ß-carotene.

Recalls and FFQs were completed before the baseline health fairs were held at the participating churches. Blood samples for assessment of serum carotenoids and total cholesterol were obtained at the health fairs. On average, recalls were administered 10 days prior to collection of the serum carotenoid samples and FFQs were completed 12 days prior to collection of serum samples. Whether the FFQ preceded or followed the 24-hour recall varied across participants.

Serum carotenoids.
Levels of the five major carotenoids (lycopene, lutein, cryptoxanthin, α-carotene, and ß-carotene) were measured in extracted serum using high performance liquid chromatography (47). Assays were performed at the Centers for Disease Control and Prevention (Nutrition Biochemistry Branch, Division of Environmental Health Laboratory Science). Carotenoid values, which were obtained from 813 participants, were similar to those reported for a sample of African-American women recruited from an inner city hospital in Atlanta (19). Total cholesterol was measured in nonfasting capillary blood samples using the Johnson and Johnson/Kodak DT60 desktop analyzer (Johnson and Johnson, New Brunswick, New Jersey; Kodak, Rochester, New York). Cholesterol results were provided to participants on-site.

Other variables assessed
Income was assessed using an eight-category ordinal item with answers ranging from <$10,000 per year to >$70,000 per year. Education categories were collapsed into two groups, "less than college" and "started/completed college." Marital status was classified as "single" or "married/living with partner." Use of cigarettes and alcohol in the past 30 days was assessed with single items. Use of vitamin supplements in the past year was assessed with a single item containing three categories: never; yes, not regularly; and yes, regularly. The latter two groups were collapsed for the current analyses.

Data analysis
We transformed values for dietary variables (i.e., servings of fruits and vegetables and carotenoid levels) and serum carotenoids to normalize their distributions. Natural logarithmic or square root transformations were used, depending on which method better improved the distribution. Mean levels presented in table 1 are raw, untransformed values, whereas all correlations shown in subsequent tables are based on transformed values. Correlations between dietary variables and serum carotenoid levels are reported separately by gender, smoking status, alcohol use, vitamin supplementation, and education, because these factors have been shown either to affect serum

carotenoid levels or to moderate the association between self-reported diet and nutritional biomarkers (24, 26, 27, 32, 48). Correlations are also reported separately for FFQs and recalls administered within 1 week of serum sample collection, since serum carotenoid levels are thought to reflect recent intake. Results obtained using serum carotenoid residuals regressed on serum total cholesterol and using 24-hour recall carotenoids regressed on total kilocalories did not differ appreciably from analyses using unadjusted values, and are not reported. All statistical analyses were performed using the Statistical Package for the Social Sciences, version 9.0 (49. To test whether pairs of correlations (e.g., males vs. females) were statistically different, we used the Fisher transform method for two independent correlations as recommended by Hayes (50). Finally, we conducted analyses using various combinations of assessment methods–for example, mean numbers of fruit and vegetable servings from the FFQ and 24-hour recalls.

TABLE 1. Baseline dietary intakes and serum carotenoid levels in the Eat for Life Trial, Atlanta, Georgia, 1997–1998

	Dietary carotenoid intake (µg/day)											
	Two-item FFQ* (*n* = 1,006)		Seven-item FFQ (*n* = 996)		36-item FFQ (*n* = 1,002)		Single 24-hour recall (*n* = 414)		Three 24-hour recalls (*n* = 105)		Serum carotenoid level (µg/dl) (*n* = 813)	
	Mean	SD*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lycopene	NA*		NA		2,065	2,913	2,787	6,341	2,200	2,612	18.0	8.8
Lutein	NA		NA		2,628	1,975	3,270	6,752	3,033	4,077	22.4	10.2
Cryptoxanthin	NA		NA		100	90	97	136	93	89	9.4	6.2
α-carotene	NA		NA		532	661	401	1,595	303	418	4.1	6.5
ß-carotene	NA		NA		3,650	3,041	2,867	5,948	2,578	3,089	23.6	25.3
No. of servings of fruits and vegetables per day	3.6	1.9	3.5	2.7	4.3	2.7	3.1	2.7	2.7	1.6	NA	

* FFQ, food frequency questionnaire; SD, standard deviation; NA, not applicable.

RESULTS

Sample description

A total of 1,114 individuals, all of whom were African-American, were recruited from the 15 churches. The number of participants per church averaged 69 (range, 54–104). The sample was predominantly female (72 percent), with a mean age of 43 years (range, 18–87). Participants younger than 18 years were excluded from the analyses. Fifty-three percent of the sample was married or living with a partner. Approximately half of the sample had an income of >$40,000 per year, and almost 60 percent had at least some college education. Approximately 12 percent reported 30-day cigarette use, 33 percent reported 30-day alcohol use, and 68 percent reported using vitamin supplements in the past year.

The subsample of 414 individuals who completed at least one 24-hour recall did not differ significantly from the remainder of the sample with regard to age, gender, income, marital status, cigarette use, or vitamin supplementation. However, the recall subsample was significantly less likely to have attended college (49.2 percent) than the remainder of the sample (63 percent) (χ^2 = 17.3; p = 0.001), and they were also significantly less likely to report 30-day alcohol use (26 percent vs. 36 percent) (χ^2 = 10.3; p = 0.001).

Daily servings of fruits and vegetables were found to be lower by means of the recall method (3.1 for one recall and 2.7 for three recalls) than by the three FFQ methods. The 36-item FFQ yielded the highest estimate of fruit and vegetable intake: 4.3 servings per day. Estimated dietary carotenoid levels from the 36-item FFQ were higher than estimates based on both the single recall and triplicate recalls.

Fruit and vegetable intake.

As table 2 shows, the correlations of fruit and vegetable servings with individual (excluding lycopene) and total serum carotenoid levels were generally higher for the 36-item FFQ than for the two-item and seven-item instruments. Number of servings of fruits and vegetables from three recalls yielded higher correlations with serum levels than did number of servings based on a single recall. None of the dietary assessment methods were significantly correlated with serum lycopene. Across methods, the strongest correlation of fruit and vegetable servings with serum carotenoids was generally observed for 3 days of recalls, with the 36-item FFQ and the single 24-hour recall yielding comparable correlations.

TABLE 2. Correlation of fruit and vegetable consumption (servings/day) with serum carotenoid levels in the Eat for Life Trial, Atlanta, Georgia, 1997–1998

Source of data on servings of fruits and vegetables	Correlation† with serum carotenoid values						
	Lycopene	Lutein	Crypto-xanthin	α-carotene	ß-carotene	Total carotenoids	Total carotenoids withoutlycopene

Two-item food frequency questionnaire (*n* = 782)	-0.02	0.14**	0.15**	0.23**	0.18**	0.19**	0.22**
Seven-item food frequency questionnaire (*n* = 775)	0.04	0.16**	0.25**	0.28**	0.24**	0.27**	0.29**
36-item food frequency questionnaire (*n* = 775)	0.02	0.21**	0.26**	0.34**	0.31**	0.32**	0.35**
Single 24-hour recall (*n* = 285)	0.03	0.31**	0.29**	0.33**	0.28**	0.34**	0.37**
Three 24-hour recalls (*n* = 74)	-0.15	0.41**	0.33**	0.38**	0.31**	0.35**	0.42**

** $p < 0.01$.

†Correlations were based on transformed values.

FFQ carotenoids.

Correlations of dietary carotenoid levels estimated from the 36-item FFQ with serum carotenoids are shown in table 3. Consistent with the fruit and vegetable correlations reported above, dietary lycopene was not associated with serum lycopene in the full sample or in any subsample (e.g., gender, smoking status, or education). For the entire sample, correlations with remaining specific carotenoids ranged from 0.21 for lutein to 0.40 for α-carotene. With the exception of cryptoxanthin and ß-carotene, correlations were somewhat higher for males than for females. The difference in correlation magnitude was significant for lutein. Nonsmokers showed significantly higher correlations for cryptoxanthin than smokers. Values were higher for ß-carotene but did not attain significance. There were only minimal gender differences for lutein and α-carotene. Correlations did not differ by education. Whereas correlations were marginally higher for alcohol users and vitamin users, none of the differences achieved significance. Correlations for FFQ data obtained within 7 days of the serum sample showed marginally higher values than those for the full sample, but these differences were not significant (data not shown).

TABLE 3. Correlation of dietary carotenoid intakes with serum carotenoid levels in the Eat for Life Trial, Atlanta, Georgia, 1997–1998

Source of data on	Correlation with serum levels of corresponding carotenoid

dietary carotenoid levels	All cases	Gender		Smoking		Education		Alcohol drinking in past 30 days		Vitamin use	
		Male	Female	Nonsmoker	Smoker	Less than college	Any college	No	Yes	Nonuser	User
36-item food frequency questionnaire	*(n = 802)*	*(n = 223)*	*(n = 577)*	*(n = 674)*	*(n = 87)*	*(n = 321)*	*(n = 447)*	*(n = 520)*	*(n = 265)*	*(n = 262)*	*(n = 535)*
Lycopene	0.06	0.04	0.06	0.06	0.15	0.04	0.08	0.05	0.08	0.03	0.08
Lutein	0.21**	0.35**,†	0.16**,†	0.21**	0.22*	0.19**	0.24**	0.19**	0.24**	0.20**	0.19**
Cryptoxanthin	0.35**	0.33**	0.35**	0.37**,‡	0.17‡	0.38**	0.33**	0.31**	0.40**	0.34**	0.34**
α-carotene	0.40**	0.44**	0.38**	0.39**	0.44**	0.38**	0.41**	0.39**	0.39**	0.32**	0.39**
ß-carotene	0.39**	0.39**	0.39**	0.40**	0.25*	0.40**	0.40**	0.38**	0.40**	0.34**	0.37**
Total carotenoids	0.33**	0.36**	0.32**	0.33**	0.29**	0.33**	0.35**	0.30**	0.36**	0.26**	0.33**
Total carotenoids without lycopene	0.37**	0.41**	0.36**	0.37**	0.32**	0.38**	0.39**	0.34**	0.41**	0.32**	0.35**
Single 24-hour recall	*(n = 285)*	*(n = 64)*	*(n = 214)*	*(n = 241)*	*(n = 31)*	*(n = 129)*	*(n = 133)*	*(n = 201)*	*(n = 71)*	*(n = 102)*	*(n = 174)*
Lycopene	0.11	0.08	0.14	0.15*	-0.14	0.14	0.14	0.09	0.19	0.16	0.12
Lutein	0.19**	0.17	0.19**	0.17**	0.23	0.20*	0.21*	0.13†	0.39**,†	0.24*	0.13
Cryptoxanthin	0.34**	0.50**,‡	0.30**,‡	0.35**	0.22	0.29**	0.40**	0.31**	0.46**	0.46**	0.28**
α-carotene	0.29	0.20	0.32*	0.29*	0.27	0.23*	0.37*	0.28*	0.32*	0.20*	0.33

	**		*			*	*	*	*		**
ß-carotene	0.25**	0.35*	0.23*	0.26*	0.17	0.23*	0.32*	0.23*	0.32*	0.23*	0.25**
Total carotenoids	0.31**	0.28*	0.32*	0.32**	0.18	0.18*,‡	0.42*,‡	0.32*	0.30*	0.30**	0.31**
Total carotenoids without lycopene	0.39**	0.42*	0.39*	0.39**	0.44*	0.34*	0.45*	0.40*	0.39*	0.36**	0.39**
Three 24-hour recalls[§]	*(n = 74)*	*(n = 10)*	*(n = 60)*	*(n = 59)*	*(n = 8)*	*(n = 45)*	*(n = 22)*	*(n = 46)*	*(n = 23)*	*(n = 29)*	*(n = 41)*
Lycopene	0.08	0.59‡	0.01‡	0.09	-0.33	0.00	0.32	-0.03‡	0.45*,‡	0.26	-0.02
Lutein	0.27*	0.32	0.23	0.15	0.42	0.07‡	0.48*,‡	0.22	0.30	0.17	0.33*
Cryptoxanthin	0.48**	0.78*	0.42*	0.54**	0.25	0.43*	0.63*	0.39*,‡	0.72*,‡	0.71**,‡	0.34*,‡
α-carotene	0.31**	0.03	0.32*	0.33*	0.46	0.19‡	0.57*,‡	0.21	0.44*	0.22	0.30*
ß-carotene	0.18	0.16	0.18	0.23	0.23	0.03	0.43*	0.15	0.25	0.09	0.27
Total carotenoids	0.24*	-0.03	0.27*	0.28*	0.34	-0.09†	0.62*,†	0.22	0.39	0.30	0.24
Total carotenoids without lycopene	0.40**	0.38	0.38*	0.43**	0.48	0.21†	0.68*,†	0.37*	0.44*	0.33	0.43**

* $p < 0.05$;
** $p < 0.01$.
†Correlation pairs were significantly different at $p < 0.01$.
‡Correlation pairs were significantly different at $p < 0.05$.
§ For three recalls, the third recall was completed within 7 days of collection of the serum sample. Recalls 1 and 2 may have been completed more than 7 days previously.

24-hour recall carotenoids.
Similar to the FFQ data, dietary lycopene was not significantly correlated with serum lycopene in the full sample. Gender differences were inconsistent (and nonsignificant, with the exception of cryptoxanthin) for the single recall, whereas a small cell size for males receiving three recalls

precluded interpretation of gender differences. For the single recall, differences between smokers and nonsmokers were inconsistent. There were insufficient smokers who received three recalls to interpret group differences. For both one and three recalls, individuals reporting at least some college education showed stronger correlations than those reporting less than a college education. Differences were significant for total carotenoids for both the single recall and three recalls, and for lutein and α-carotene for three recalls. Correlations tended to be higher for alcohol users than for nonusers, with significant differences for lutein in the single recall group and for lycopene and cryptoxanthin in the multiple recall group. There was no consistent pattern in correlations based on vitamin use, although there was a significant difference for cryptoxanthin in the multiple recall group. For individuals who received their single recall and those who received their third recall (first and second recalls may have been conducted more than 1 week prior to the serum sample) within 7 days of collection of their serum sample, correlations were not significantly different from those of persons receiving calls earlier (data not shown).

Differences in assessment methods presented in tables 2 and 3 may have been related to sampling bias, since there was only partial overlap among the subjects who completed each instrument. Table 4 presents correlations of fruit and vegetable intake and dietary carotenoids with serum carotenoids for the subsample that completed all FFQs and three dietary recalls. Similar to the patterns observed in tables 2 and 3, correlations of fruit and vegetable servings and serum carotenoids were higher for the 36-item FFQ than for the two-item and seven-item instruments and for three recalls compared with one recall. With regard to dietary carotenoids, correlations with serum levels were generally higher for the 36-item FFQ than for either multiple recalls or a single recall.

TABLE 4. Correlation of fruit and vegetable consumption (servings/day) and dietary carotenoid intakes with serum carotenoid levels among persons receiving three 24-hour recalls (n = 68) in the Eat for Life Trial, Atlanta, Georgia, 1997–1998

Source of data	Correlation† with serum carotenoid values						
	Lycopene	Lutein	Crypto-xanthin	α-carotene	ß-carotene	Total carotenoids	Total carotenoids without lycopene
Two-item food frequency questionnaire							
Fruit and vegetable consumption	0.17	0.28*	0.27*	0.29*	0.31*	0.35**	0.34**
Intake of corresponding carotenoid	NA‡	NA	NA	NA	NA	NA	NA

Seven-item food frequency questionnaire							
Fruit and vegetable consumption	-0.08	0.03	0.19	0.24	0.14	0.16	0.19
Intake of corresponding carotenoid	NA	NA	NA	NA	NA	NA	NA
36-item food frequency questionnaire							
Fruit and vegetable consumption	0.24	0.30*	0.43**	0.52**	0.46**	0.53**	0.53**
Intake of corresponding carotenoid	0.05	0.27*	0.50**	0.49**	0.44**	0.52**	0.50*
Single 24-hour recall							
Fruit and vegetable consumption	-0.15	0.32**	0.22	0.42**	0.31*	0.32**	0.39**
Intake of corresponding carotenoid	0.19	0.15	0.39**	0.39**	0.26*	0.42**	0.36**
Three 24-hour recalls							
Fruit and vegetable consumption	-0.14	0.42**	0.27**	0.39*	0.35**	0.36**	0.43**
Intake of corresponding carotenoid	0.08	0.25*	0.63**	0.32*	0.19	0.27*	0.41**

* $p < 0.05$;
** $p < 0.01$.
†Correlations were based on transformed values.
‡NA, not applicable.

In practice, researchers may choose to utilize multiple assessment methods. Therefore, we carried out analyses using various composite measures of fruit and vegetable intake as well as dietary carotenoids. As table 5 shows, correlations between fruit and vegetable intake and dietary carotenoid and serum levels were slightly improved if both FFQ and recall data were used. Based on the sample that completed all FFQs and three recalls, it appears that adding data from a single recall to the FFQ data improved validity as much as using data from three recalls.

TABLE 5. Correlation of fruit and vegetable consumption (servings/day) and dietary carotenoid intakes based on composite values from multiple assessment methods with serum carotenoid levels in the Eat for Life Trial, Atlanta, Georgia, 1997–1998

	Correlation† with serum carotenoid values	
	Total carotenoids	Total carotenoids without lycopene
Entire study sample		
Mean fruit and vegetable consumption from three FFQs‡ (*n* = 798)	0.32**	0.35**
Mean fruit and vegetable consumption from three FFQs and one 24-hour recall (*n* = 206)	0.39**	0.42**
Mean fruit and vegetable consumption from three FFQs and three 24-hour recalls (*n* = 74)	0.41**	0.47**
Mean dietary carotenoid intake from the 36-item FFQ and one recall (*n* = 206)	0.27**	0.31**
Mean dietary carotenoid intake from the 36-item FFQ and three recalls (*n* = 74)	0.49**	0.51**
Subsample of persons who completed three recalls and all three FFQs (*n* = 68)		
Mean fruit and vegetable consumption from three FFQs	0.43**	0.44**
Mean fruit and vegetable consumption from three FFQs and one recall	0.41**	0.47**
Mean fruit and vegetable consumption from three FFQs and three recalls	0.44**	0.49**
Mean dietary carotenoid intake from the 36-item FFQ and one recall	0.55**	0.58**
Mean dietary carotenoid intake from the 36-item	0.53**	0.55**

FFQ and three recalls

** $p < 0.01$.
†Correlations were based on transformed values.
‡FFQ, food frequency questionnaire.

DISCUSSION

In this study, several methods of assessing fruit and vegetable intake were compared with serum carotenoid levels. Assuming that higher correlations of dietary variables with serum levels can be interpreted as an indication of greater validity, it appears that the 36-item FFQ produces somewhat more valid estimates of fruit and vegetable intake than the two-item instrument or the seven-item instrument. While the greater number of items and the specificity of each item (e.g., embedded portion size) represent likely explanations for the increased validity of the longer instrument, each instrument also differed with regard to the recall time frame. The 36-item measure assessed intake in the past week, whereas the seven-item measure was based on past-month intake and the two-item measure was based on usual intake. Comparison of these instruments using similar recall periods is needed to determine whether the added validity of the 36-item measure can be attributed to its length, its portion size detail, or the recall time frame.

Correlations of fruit and vegetable servings (and, to a lesser degree, dietary carotenoids) with serum carotenoid levels based on three recalls were marginally higher than correlations based on a single recall. Additionally, as table 5 shows for the restricted sample, there was no substantial increment in validity when three recalls were combined with FFQ data relative to adding data from a single recall. Given that 3 days of recalls should produce a better estimate of actual intake than a single recall, the relatively small increase in validity yielded by three recalls versus one (which was also reflected in low intraclass correlation coefficients) was somewhat surprising. A considerably greater number of recall days may be needed to more accurately assess dietary carotenoid levels (12, 51, 52).

Servings of fruits and vegetables and dietary carotenoid levels assessed by both FFQ and 24-hour recall were generally uncorrelated with serum lycopene. This is consistent with several prior studies that have found weak, even inverse correlations of fruit and vegetable intake and dietary lycopene with serum lycopene (18, 19, 28, 53). The mean daily lycopene intake in our sample–2,065–2,787 μg, depending on the assessment method used–was toward the lower end of the range of intakes found in other published studies (7,636 μg (20), 4,280 μg (54), 3,056 μg (34), 3,353 μg (34), 2,407 μg (29), and 257 μg (19)), some of which found a positive association with serum lycopene.

The primary sources of lycopene are tomatoes, tomato juice, ketchup, watermelon, pink grapefruit, and apricots (18, 45). Lycopene is also consumed in mixed dishes such as pizza and tomato-based sauces. These mixed foods were not included in the 36-item FFQ, which might explain the low diet-serum correlation for this instrument. However, such foods would have been detected in the 24-hour recalls, which also showed low diet-serum correlations. Since dietary lycopene is derived from relatively few foods, its intake may be more unstable. This variability was reflected in the intraclass correlation coefficient of zero that was observed across the 3 recall days for lycopene.

Serum lycopene also appears to be less responsive to dietary intake than the other major carotenoids (29, 53, 55), which could also explain the low diet-serum correlations. The bioavailability of lycopene appears to be dependent on several factors (53). There is some evidence that absorption of lycopene is greater when the food product is heated during processing or immediately prior to consumption (53). Thus, consumption of raw tomatoes may not be strongly reflected in serum carotenoid levels. Additionally, a high intake of ß-carotene may affect lycopene absorption and transport (53). Validation of dietary assessments with serum lycopene may not be warranted.

Diet-serum correlations were not appreciably or consistently higher among nonsmokers than among smokers in either the FFQ or the 24-hour recall data. Whereas several studies have found stronger diet-serum correlations among nonsmokers (19, 27, 32), these effects have not been consistent (26). Consistent gender differences in validity were not evident in our sample. Results from prior studies that have examined gender differences have been mixed (20, 24, 26, 32).

The validity of the 36-item FFQ was generally as strong as both 1 and 3 days of dietary recalls. Whereas the validity of recalls was stronger for college-educated participants, the 36-item FFQ performed equally well in less educated participants. This finding, together with the lower cost and time of administration relative to recalls, suggests that this FFQ method may be preferable to dietary recalls for evaluating fruit and vegetable health interventions. Additional recalls would probably increase validity (34, 51), although the increased costs might prove prohibitive in large field trials. However, given that numbers of fruit and vegetable servings based on the 36-item measure had correlations of only 0.31 and 0.41 with 1 and 3 days of recalls, respectively (data not shown), it appears that these measures may tap different dimensions of "true" intake. Therefore, when possible, multiple methods should be used to triangulate actual intake (56, 57).

The 36-item FFQ developed for this study was based on the widely used HHHQ instrument. The question of whether the changes made to the HHHQ improved its validity could best be answered by having study participants complete both instruments. Since this was not done in the current study, we cannot determine whether the modifications improved the original instrument. The magnitude of the correlations observed with serum carotenoids from the modified FFQ was comparable to or greater than that of other studies using either the Willet instrument (18, 20, 23, 24, 54) or the original HHHQ (19, 21, 26, 30, 33, 34). Comparison with prior studies is limited by the fact that diet-serum correlations were based on global diet, not only fruit and vegetable intake, and the nutrient database used to compute carotenoid intake for our FFQ was somewhat more comprehensive than that used in most prior studies (44). While the former mitigating factor would probably result in weaker correlations in our study relative to prior work, the latter would probably have the opposite effect.

In this sample of African-American adults, a modified 36-item fruit and vegetable FFQ showed validity comparable to that of 1 and 3 days of 24-hour recalls. The 36-item FFQ yielded slightly higher validity coefficients than the shorter FFQs, and the longer form has the added benefit of providing an estimate of dietary carotenoid intake in addition to servings of fruits and vegetables. Use of this instrument or other, similar FFQs to evaluate health interventions that focus on

increasing fruit and vegetable intake may be warranted, and continued research on the validity of these and other dietary assessment instruments is encouraged.

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