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Strength of the relationships between three self-reported dietary intake instruments and serum carotenoids: the Observing Energy and Protein Nutrition (OPEN) Study

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Abstract

Objective: To assess the strength of the relationships between serum carotenoids and three self-reported dietary intake instruments often used to characterize carotenoid intake in studies of diet and disease.

Design: Participants completed a Diet History Questionnaire (DHQ), two 24 h dietary recalls (24HR), a fruit and vegetable screener and a fasting blood draw. We derived dietary intake estimates of α-carotene, β-carotene, cryptoxanthin, lutein, zeaxanthin and lycopene from each diet instrument and calculated sex-specific multivariate correlations between dietary intake estimates and their corresponding serum values.

Setting: Montgomery County, Maryland, USA.

Subjects: Four hundred and seventy women and men aged 40–69 years in the National Cancer Institute's Observing Protein and Energy Nutrition (OPEN) Study.

Results: Serum carotenoids correlated more strongly with the DHQ ($r = 0{\cdot}34$–$0{\cdot}54$ for women; $r = 0{\cdot}38$–$0{\cdot}56$ for men) than with the average of two recalls ($r = 0{\cdot}26$–$0{\cdot}47$ for women; $r = 0{\cdot}26$–$0{\cdot}40$ for men) with the exception of zeaxanthin, for which the correlations using recalls were higher. With adjustment for within-person variation, correlations between serum carotenoids and recalls were greatly improved ($r = 0{\cdot}38$–$0{\cdot}83$ for women; $r = 0{\cdot}42$–$0{\cdot}74$ for men). In most cases, correlations between serum carotenoids and the fruit and vegetable screener resembled serum–DHQ correlations.

Conclusions: Evidence from the study provides support for the use of the DHQ, a fruit and vegetable screener and deattenuated recalls for estimating carotenoid status in studies without serum measures, and draws attention to the importance of adjusting for intra-individual variability when using recalls to estimate carotenoid values.

Keywords
Diet
Carotenoids
Diet surveys
Biological markers

A large body of literature has suggested that dietary patterns rich in fruits and vegetables, the main source of naturally occurring pigments with antioxidant capacity called carotenoids, are important for the prevention of CVD, diabetes and some cancers[1]. In large population studies, the majority of data relating diet to individual risk of disease relies on self-report assessment methods[2] such as the FFQ, which asks about habitual intake over the past 6 to 12 months, or the 24 h dietary recall (24HR), which inquires about intake of foods in the past day. However, self-report methods for assessing diet are prone to measurement error, and misclassification of exposures and covariates can create bias in estimates of diet–disease associations[3–6].

Blood carotenoid concentrations are thought to be useful biomarkers of fruit and vegetable intake. Due to a variety of factors that affect concentrations of carotenoids in the serum, such as the characteristics of foods, as well as host factors such as body size, gender, smoking status, cholesterol level and inter-individual variability in absorption, carotenoid concentrations cannot be directly translated to fruit and vegetable intake[7]. Nevertheless, correlations with concentrations may provide some degree of face validity for carotenoid intake estimates from dietary assessment instruments.

Given the feasibility of using self-report measures in large studies, ongoing evaluation of how well our self-reported dietary measures compare with blood estimates

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of carotenoids is important for interpretation of results in studies examining carotenoid–disease associations[8]. Past validation studies of this kind have typically evaluated two self-report methods of assessment and the majority of these studies have been performed in relatively small subsamples. Among 470 women and men in the National Cancer Institute's (NCI) Observing Protein and Energy Nutrition (OPEN) Study, we had the opportunity to evaluate the utility of various commonly used dietary instruments, and compared the correlations between self-reported intake of carotenoids estimated from an FFQ, recalls and a novel fruit and vegetable screener and their corresponding serum values. We also evaluated the impact of energy adjustment using doubly labelled water (DLW) *v.* estimates of energy intake from self-report measures.

Experimental methods

Sample and study design

OPEN was conducted by the NCI from September 1999 to March 2000. A complete description of the study can be found elsewhere[9]. The original purpose of OPEN was to assess dietary measurement error by comparing measurements obtained via self-reported dietary instruments with unbiased biomarkers of energy (DLW) and protein intake (urinary N) among 484 men and women. The current investigation was restricted to the 470 participants who completed a Diet History Questionnaire (DHQ; baseline visit), at least one of two recalls (baseline and third visits), a fruit and vegetable screener and a blood draw (second visit; see Fig. 1). The fourteen participants excluded from the analysis were slightly older and more overweight than the 470 who were included.

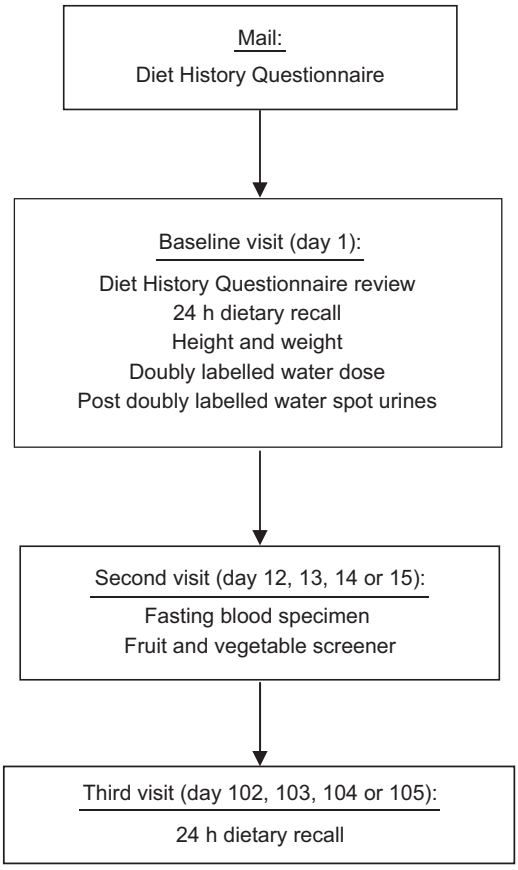

Fig. 1 Study flow and activities, the Observing Protein and Energy Nutrition (OPEN) Study, September 1999–March 2000

Measures

Diet History Questionnaire

In advance of the first visit, participants were mailed and asked to complete a DHQ, an FFQ developed and evaluated at the NCI[10]. The DHQ was collected on the first day of the study. Participants reported their usual frequency of intake and portion size of 124 food items over the last 12 months. For forty-four of the foods, participants were asked about seasonal intake, food type (e.g. low fat, lean, diet, caffeine free) and/or fat uses or additions. The DHQ also featured six additional questions about use of low-fat foods, four summary questions, and ten dietary supplement questions, including one on the dose and frequency of β-carotene supplement intake.

Each food item in the DHQ includes values of fruits and vegetables in pyramid servings (PYR) based on US Department of Agriculture (USDA) data[11]. One PYR of fruit was equivalent to 1 whole fruit, $\frac{1}{2}$ cup of chopped fruit or $\frac{3}{4}$ cup of fruit juice. One PYR of vegetables was equivalent to 1 cup of raw, leafy vegetables, $\frac{1}{2}$ cup of other vegetables or $\frac{3}{4}$ cup of vegetable juice[11]. Potatoes were not included in the calculation of vegetable intake. Although fruit and vegetable intake recommendations now use the standard unit of a cup (http://www.choosemyplate.org) instead of a PYR, the rankings of participants' fruit and vegetable intake are not expected to differ between methods[12].

To obtain dietary carotenoid values from DHQ fruit and vegetable intake data, we matched food codes from the 1994–96 Continuing Survey of Food Intakes by Individuals (CSFII) to similar foods in the nutrient database of the Nutrition Data Systems for Research (NDS-R) from the University of Minnesota (Nutrition Coordinating Center, Minneapolis, MN, USA)[13,14].

24 h dietary recalls

Participants completed highly standardized recalls utilizing the five-pass method, developed by the USDA for use in national dietary surveillance[15]. At the baseline (first day) and third (days 102–105) visits, trained interviewers administered recalls in-person to participants. Participants were asked about their food and supplement intake from midnight to midnight the previous day, as in the National Health and Nutrition Examination Survey (NHANES). Similar to the DHQ, the 24HR probed for specific dose for β-carotene supplements. To calculate

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carotenoid values, the 24HR data were coded and linked to a nutrient database, the Food Intake Analysis System version 3·99 (Health Science Center, University of Texas, Houston, TX, USA), which obtained its database from updates to CSFII[16].

Fruit and vegetable screener

At the second visit (day 12, 13, 14 or 15), participants completed a Multifactor Screener[17], a seventeen-item dietary instrument which asked frequency of intake of seven fruit and vegetable food groups in the past month (see Appendix). CSFII data were used to generate sex/age-specific portion sizes of fruit and vegetable intake in PYR and assign dietary carotenoid values in micrograms (μg/PYR). The Multifactorial Screener was developed using national data and its fruit and vegetable component was strongly correlated with estimated true intake in the OPEN study, at about 0·6–0·7 among men and 0·5–0·8 among women[17].

Serum

Blood specimens were collected for all participants at the second visit (day 12, 13, 14 or 15) and were processed and stored at −80°C until thawed for laboratory analysis. Samples were sent to Craft Technologies (Wilson, NC, USA) for analyses of carotenoids by HPLC. The laboratory provided results for α-carotene, *cis*- and *trans*-β-carotene, *cis*- and *trans*-β-cryptoxanthin, lutein, zeaxanthin, and *cis*- and *trans*-lycopene. Northwest Lipid Metabolism and Diabetes Research Laboratories (Seattle, WA, USA) performed the lipid analyses and reported results for cholesterol and TAG. For both carotenoid and lipid analyses, we inserted 10% blind quality control samples to monitor performance of the laboratory assays in each batch of study participants' samples.

The CV for external quality control samples were acceptable for most of the carotenoids and the lipids (CV (%): 4·9 for *trans*-β-carotene; 8·9 for α-cryptoxanthin; 7·8 for β-cryptoxanthin; 3·0 for lutein; 6·5 for zeaxanthin; 3·4 for *trans*-lycopene; 4·7 for *cis*-lycopene; 5·9 for cholesterol; 3·8 for TAG). The CV for α-carotene (13·2%) was higher than for most other carotenoids, likely due to low concentrations in the blood. Given its quality control results, we chose to not include *cis*-β-carotene in our analyses (CV = 27·5%).

Doubly labelled water

Total energy expenditure was measured by DLW. The DLW studies are described in detail elsewhere[18]. Briefly, we used a five-specimen protocol, with total body water measured by the plateau method[19]. At the baseline visit (day 1), DLW was given orally at a dose of approximately 0·12 g of 10 atom% ^{18}O-labelled water and 0·12 g of 99·9% ^{2}H-labelled water per kilogram of estimated total body water along with a subsequent 50 ml water rinse of the dose bottle[18]. After consuming nothing for 1 h, participants were then allowed to consume 200–400 ml of juice, a liquid replacement meal, or coffee during the next 2 h[18]. Volume of liquids consumed and time of consumption were recorded. Urine specimens were collected at 2, 3 and 4 h after the dose. The 2 h specimen was discarded. Total energy expenditure was calculated according to Racette *et al.*[19] and by using the modified Weir equation, assuming a respiratory quotient of 0·86.

Other covariates

Age, race/ethnicity and education level were obtained in advance of the baseline visit from the telephone screening interview. At the baseline visit (day 1), trained staff measured participants' weight and height while they were wearing light indoor clothing and no shoes. All measurements were performed twice and averaged for a final value. If weight measurements differed by 0·3 kg or height measurements differed by 0·5 cm or more, then a third measurement was taken and used for final weight and height values. BMI was calculated as kg/m^2. For the DHQ and fruit and vegetable screener, energy was estimated from the DHQ, while for the 24HR, energy was estimated from the average of two recalls.

Statistical analysis

We chose to present all data stratified by sex, because of past evidence showing under-reporting is more common among women than men[20–26]. All analyses were executed using the SAS statistical software package version 9·1·3 (SAS Institute Inc., Cary, NC, USA). Geometric means and 95% confidence intervals were calculated for log-transformed serum and dietary carotenoid estimates and TAG. Means were reported for cholesterol due to its normal distribution.

Sex-specific energy-adjusted and multivariate-adjusted Spearman correlations between serum carotenoids and dietary carotenoids from the DHQ, average of the recalls and fruit and vegetable screener were performed using the PROC CORR procedure. For the recalls, we also calculated multivariate-adjusted sex-specific Pearson correlations using PROC CORR and deattenuated the estimates by adjusting for intra-individual variation in the recalls[27]. Deattenuated correlations were calculated by multiplying the Pearson correlation by $\sqrt{\mathrm{var}(\bar{R})/\mathrm{cov}(R_1, R_2)}$, where R_1 and R_2 are the first and second applications of the 24HR, and $\bar{R}$ is the mean of R_1 and R_2.

Correlations of diet measures with combined *cis*- and *trans*-lycopene, combined lutein and zeaxanthin, and combined α- and β-cryptoxanthin were not reported because individual serum carotenoid measures correlated as well as or better than the aforementioned combined measures and are often of interest in diet–disease associations (e.g. lutein and age-related macular degeneration). For the DHQ and recalls, for β-carotene, we also performed analyses with and without incorporating self-reported β-carotene supplement use.

Covariates considered in the multivariate correlation models were age, energy, serum total cholesterol, serum TAG, BMI, race/ethnicity and education. Given that the large majority of our population was not currently smoking

(89 %), and that additional control for smoking did not affect the magnitude of correlations, we did not include smoking in our model building. Potential covariates were assessed via likelihood ratio tests ($\alpha = 0{\cdot}05$) and examination of residuals in linear regression models. Our final model included diet-derived energy, BMI, serum total cholesterol and TAG. Substituting energy derived by DLW did not result in substantial changes in magnitude of the correlations.

In an attempt to adjust for potential under- or over-reporting of individual fruits and vegetables on the DHQ, we performed a fruit and vegetable adjust procedure as described by Block with the DHQ data[28]. The adjustment did not affect the previous correlations obtained, so the original estimates are presented.

Results

Descriptive statistics of the sample are presented in Table 1. On average, both men and women were 53–54 years of age, non-Hispanic white, overweight, and reported consuming 2–3 servings of fruit and 2–4 servings of vegetables daily depending on the dietary assessment measure. Men had higher mean energy intake than women.

Table 2 shows the geometric means of self-reported dietary carotenoid intakes obtained from the DHQ, recalls and screener, as well as concentrations of serum carotenoids and lipids. Mean dietary intakes of all individual carotenoids were highest from the DHQ and lowest from the screener. Screener estimates were higher than 24HR estimates for cryptoxanthin (men and women) and lycopene (women only).

Serum carotenoids correlated more strongly with DHQ dietary carotenoids than the average of 24HR dietary carotenoids except for zeaxanthin, for which 24HR correlations were stronger (Table 3). Deattenuation of the correlations between recalls and serum carotenoids to account for within-person variability in diet resulted in substantially higher correlations, as expected. Correlations of serum and diet *trans*-β-carotene improved slightly when specifically measured supplemental intake was taken into account. In most cases, multivariate correlations of serum carotenoids with the screener-derived carotenoid estimates resembled the serum–DHQ correlations. Overall, energy adjustment and multivariate adjustment improved correlations between serum and dietary measures.

Discussion

The present study makes a contribution to the field of dietary assessment in that we compared three commonly

Table 1 Characteristics of the study participants: 470 women and men, the Observing Protein and Energy Nutrition (OPEN) Study, September 1999–March 2000

	Women				Men			
	n	%	Mean	SD	*n*	%	Mean	SD
No. of participants	217				253			
Race/ethnicity								
Non-Hispanic white	170	78			218	86		
Non-Hispanic black	21	10			7	3		
Hispanic	3	1			7	3		
Other	23	11			21	8		
Age (years)			53	8			54	8
Measured BMI (kg/m^2) at baseline			28	6			28	4
Fruit and vegetable intake (no potato)								
DHQ (PYR/d)			6·6	3·6			6·8	4·1
Recalls (PYR/d)			5·1	2·7			5·9	3·0
F&V screener (PYR/d)			4·2	1·6			4·6	1·7
Fruit intake								
DHQ (PYR/d)			2·9	2·2			2·8	2·4
Recalls (PYR/d)			2·2	1·7			2·5	2·0
F&V screener (PYR/d)			2·1	1·3			2·2	1·5
Vegetable intake (no potato)								
DHQ (PYR/d)			3·8	2·1			4·0	2·7
Recalls (PYR/d)			2·9	1·9			3·4	1·9
F&V screener (PYR/d)			2·1	0·7			2·4	0·6
Total energy from DHQ								
kJ/d			6799	2707			8929	4042
kcal/d			1625	647			2134	966
Total energy from 24HR								
kJ/d			8280	2226			10 954	3130
kcal/d			1979	532			2618	748
Total energy from DLW								
kJ/d			9636	1640			12 150	2222
kcal/d			2303	392			2904	531

DHQ, Diet History Questionnaire; PYR, pyramid servings; 24HR, 24 h dietary recall; F&V, fruit and vegetable; DLW, doubly labelled water.

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Table 2 Unadjusted geometric means and 95 % confidence intervals of carotenoids and lipids among 470 women and men, the Observing Protein and Energy Nutrition (OPEN) Study, September 1999–March 2000

	Women		Men	
Measure	Geometric mean	95 % CI	Geometric mean	95 % CI
Diet (μg)				
α-Carotene (diet)				
DHQ	574	504, 654	501	444, 566
Recalls	237	183, 308	251	197, 319
F&V screener	206	184, 230	202	183, 224
β-Carotene (diet)				
DHQ	3112	2807, 3449	2637	2397, 2901
Recalls	2126	1849, 2444	2246	1974, 2555
F&V screener	980	889, 1080	951	869, 1041
β-Carotene (diet + supplements)				
DHQ	3518	3194, 3876	2919	2669, 3193
Recalls	2534	2223, 2888	2539	2250, 2866
Cryptoxanthin (diet)				
DHQ	139	125, 155	132	119, 146
Recalls	83	66, 104	76	61, 94
F&V screener†	100	89, 112	96	86, 107
Lutein + zeaxanthin (diet)				
DHQ	2404	2174, 2657	2165	1973, 2375
Recalls	1667	1501, 1852	1946	1765, 2144
F&V screener	779	712, 853	765	704, 831
Lycopene (diet)				
DHQ	4215	3838, 4628	5641	5173, 6152
Recalls	281	139, 568	1151	599, 2210
F&V screener	741	672, 818	734	670, 803
Blood (μg/dl)				
α-Carotene	7·0	6·4, 7·6	5·5	5·0, 5·9
Trans-β-carotene	24·7	22·4, 27·2	18·3	16·7, 20·0
α-Cryptoxanthin	2·4	2·3, 2·5	2·1	1·9, 2·2
β-Cryptoxanthin	11·0	10·1, 11·9	9·7	9·0, 10·4
Lutein	12·5	11·7, 13·4	10·9	10·2, 11·6
Zeaxanthin	3·1	2·9, 3·3	2·9	2·7, 3·1
Trans-lycopene	20·6	19·1, 22·2	21·9	20·4, 23·4
Cis-lycopene	20·3	18·9, 21·8	22·0	20·6, 23·4
Cholesterol	210‡	205, 215	197‡	192, 202
TAG	107	99, 115	129	120, 138

DHQ, Diet History Questionnaire; 24HR, 24 h dietary recall; F&V, fruit and vegetable
†Only β-cryptoxanthin is calculated from the F&V screener.
‡Means (not geometric means) are reported for cholesterol.

used self-report measures of fruit and vegetable intake with a spectrum of serum carotenoids. The study featured high-quality serum carotenoid measures, a larger sample size, and included an evaluation of a fruit and vegetable screener that was later used in national health surveys[29,30]. Also, unlike past validation work in this area, we reported on the effect of adjusting for within-person variation when examining correlations between the average of multiple recalls and serum carotenoids and had the ability to evaluate the effect of adjustment for energy as assessed by DLW.

The geometric means of serum carotenoids (α-carotene, β-carotene, β-cryptoxanthin, *trans*-lycopene) and cholesterol observed in our study were similar to those in NHANES III[31] and the nationally representative sample in the Eating at America's Table Study (EATS)[32]. Our sample's mean serum TAG was slightly lower than the NHANES estimate[31].

Similar to other studies that formally examined validity of both FFQ and 24HR measurements[32,33], our OPEN data showed modest to strong correlations between FFQ and average 24HR diet and serum measures for provitamin A carotenoids (i.e. α-carotene, β-carotene, α-cryptoxanthin, β-cryptoxanthin) and modest correlations for lutein, and *trans*- and *cis*-lycopene. Consistent with our previous investigation in EATS (n 163)[32], estimates of mean dietary intakes of all individual carotenoids were higher for the DHQ than for the average of recalls. In other past studies examining at least one FFQ and multiple recalls[33–39], no particular method of dietary assessment produced consistently stronger correlations with individual serum carotenoids.

Unlike the DHQ, which is designed to measure usual intake over an extended period, the 24HR is designed to measure intake on a given day and is expected to be more highly correlated with true intake on that day than with true usual (long-term average) intake. Consistent with past studies which have formally examined components of variation in reported intake[27,40], a large part of the variability of intake as measured by 24HR in our study was due to day-to-day within-person variation. In order to better judge the 24HR's performance, we calculated deattenuated (Pearson) correlations that remove

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Table 3 Correlations† of serum and dietary carotenoids among 470 women and men, the Observing Protein and Energy Nutrition (OPEN) Study, September 1999–March 2000

	Women (*n* 217)							Men (*n* 253)						
	DHQ	*P*	Recalls	*P*	$Recalls_{Deattenuated}$	Screener	*P*	DHQ	*P*	Recalls	*P*	$Recalls_{Deattenuated}$	Screener	*P*
Diet α-carotene to serum α-carotene														
Unadjusted	0·44	***	0·36	***	0·71	0·33	***	0·39	***	0·29	***	0·40	0·36	***
Energy adjusted	0·50	***	0·37	***	0·73	0·35	***	0·43	***	0·29	***	0·41	0·37	***
Multivariate adjusted†	0·54	***	0·37	***	0·72	0·33	***	0·43	***	0·31	***	0·45	0·35	***
Diet β-carotene to serum *trans*-β-carotene														
Unadjusted	0·26	***	0·35	***	0·67	0·28	***	0·30	***	0·23	***	0·45	0·31	***
Energy adjusted	0·33	***	0·38	***	0·71	0·30	***	0·36	***	0·25	***	0·53	0·33	***
Multivariate adjusted†	0·37	***	0·35	***	0·69	0·28	***	0·37	***	0·26	***	0·55	0·30	***
Diet + supplemental β-carotene to serum *trans*-β-carotene														
Unadjusted	0·28	***	0·37	***	0·65			0·37	***	0·30	***	0·55		
Energy adjusted	0·35	***	0·39	***	0·68			0·43	***	0·31	***	0·63		
Multivariate adjusted†	0·39	***	0·36	***	0·66			0·44	***	0·33	***	0·67		
Diet cryptoxanthin to serum α-cryptoxanthin														
Unadjusted	0·38	***	0·32	***	0·55	0·38	***	0·41	***	0·31	***	0·43	0·45	***
Energy adjusted	0·38	***	0·32	***	0·57	0·38	***	0·42	***	0·31	***	0·43	0·45	***
Multivariate adjusted†	0·37	***	0·30	***	0·54	0·37	***	0·46	***	0·31	***	0·42	0·46	***
Diet cryptoxanthin to serum β-cryptoxanthin														
Unadjusted	0·52	***	0·47	***	0·77	0·55	***	0·48	***	0·38	***	0·55	0·48	***
Energy adjusted	0·53	***	0·47	***	0·81	0·55	***	0·51	***	0·38	***	0·56	0·50	***
Multivariate adjusted†	0·54	***	0·47	***	0·83	0·54	***	0·56	***	0·39	***	0·56	0·50	***
Diet lutein/zeaxanthin to serum lutein														
Unadjusted	0·30	***	0·33	***	0·52	0·31	***	0·31	***	0·34	***	0·56	0·31	***
Energy adjusted	0·31	***	0·34	***	0·53	0·31	***	0·36	***	0·36	***	0·61	0·33	***
Multivariate adjusted†	0·34	***	0·35	***	0·55	0·29	***	0·37	***	0·38	***	0·64	0·30	***
Diet lutein/zeaxanthin to serum zeaxanthin														
Unadjusted	0·08	ns	0·21	**	0·30	0·12	NS	0·13	NS	0·17	*	0·35	0·10	NS
Energy adjusted	0·05	ns	0·22	**	0·31	0·11	NS	0·13	*	0·17	**	0·37	0·11	NS
Multivariate adjusted†	0·08	ns	0·24	***	0·31	0·09	NS	0·13	*	0·19	**	0·36	0·08	NS
Diet lycopene to serum *trans*-lycopene														
Unadjusted	0·29	***	0·26	***	0·65	0·11	NS	0·30	***	0·30	***	0·66	−0·02	NS
Energy-adjusted	0·31	***	0·26	***	0·65	0·11	NS	0·33	***	0·30	***	0·66	−0·03	NS
Multivariate adjusted†	0·35	***	0·26	***	0·63	0·11	NS	0·38	***	0·31	***	0·71	−0·06	NS
Diet lycopene to serum *cis*-lycopene														
Unadjusted	0·33	***	0·28	***	0·63	0·16	*	0·30	***	0·30	***	0·67	0·06	NS
Energy adjusted	0·36	***	0·28	***	0·63	0·16	*	0·37	***	0·31	***	0·67	0·06	NS
Multivariate adjusted†	0·41	***	0·29	***	0·61	0·17	*	0·44	***	0·33	***	0·73	0·02	NS

*$P < 0·05$; **$P < 0·01$; ***$P < 0·001$.
†Models are adjusted for energy, serum total cholesterol, serum TAG and BMI.

the effect of day-to-day variability. Before deattenuation, correlations between the average of two 24HR and the serum biomarker were usually lower than the corresponding correlations for the DHQ, while after deattenuation they were usually substantially higher than those for the DHQ. These results underscore the need to adjust for day-to-day variability when estimating diet–disease relationships in epidemiological studies that use the 24HR to assess diet, and thus the need for at least two recalls in at least a subsample of the individuals in the study[27].

Our study was the first to evaluate how well a fruit and vegetable screener estimates some dietary carotenoids (α-carotene, β-carotene, cryptoxanthin, lutein/zeaxanthin and lycopene) and how this performance compares with that of the 24HR and the DHQ. For α-carotene, *trans*-β-carotene, α-cryptoxanthin, β-cryptoxanthin and lutein, correlations with the screener were only slightly lower than with the DHQ, pointing to the potential value of inclusion of this screener in cross-sectional or longitudinal studies when respondent burden is a main concern and there is interest in estimating carotenoids.

Measurement error models are often used to estimate Pearson correlations between reported and true usual intake of dietary components[41]. Such models require a valid reference instrument such as DLW or urinary N that is unbiased at the individual level. Concentration biomarkers such as serum carotenoids have person-specific biases related to bioavailability, absorption, metabolism and other factors, so are not valid reference instruments and cannot be used to estimate the correlation of true and reported intake[41]. The correlation between a serum carotenoid and reported intake can, however, be considered a lower bound of true and reported intake[42].

In the absence of blood data in many large studies, we are often reliant on self-report dietary measures of carotenoid or fruit and vegetable intake. Our study provided evidence that the DHQ, deattenuated recalls or (in some cases) a fruit and vegetable screener may be useful measures for estimating carotenoid status in studies without serum measures. Further, dietary energy was shown to be a good surrogate for DLW energy in these analyses. Ongoing research is needed on how to use biomarkers to complement self-report measures in prediction of disease or survival from disease[43].

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Appendix

Seven items asked on fruit and vegetable consumption as part of the seventeen-item Multifactorial Screener[17,44]

How many times per day, week, or month do you usually eat (or drink):

1. 100 % fruit juice such as orange, grapefruit, apple, and grape juices? Do not count fruit drinks such as Kool-Aid, lemonade cranberry juice cocktail, Hi-C, and Tang.
2. fruit? Count fresh, frozen, or canned fruit. Do not count juices.
3. lettuce or green leafy salad, with or without other vegetables?
4. French fries, home fries, or hash brown potatoes?
5. other white potatoes? Count baked potatoes, boiled potatoes, mashed potatoes, and potato salad. Do not include yams or sweet potatoes.
6. cooked dried beans, such as refried beans, baked beans, bean soup, and pork and beans?
7. other vegetables? Count any form of vegetable: raw, cooked, canned or frozen. Do not count: lettuce salads, white potatoes, cooked dried beans, rice.

Frequency response categories are: never, 1–3 times last month, 1–2 times per week, 3–4 times per week, 5–6 times per week, 1 time per day, 2 times per day, 3 times per day, 4 or more times per day.