Fruit and vegetable intakes in relation to plasma nutrient concentrations in women in Shanghai, China

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Abstract

Objective: To evaluate the validity of fruit and vegetable intakes as it relates to plasma carotenoid and vitamin C concentrations in Chinese women, using three classification schemes.
Design: Intakes were calculated using an interviewer-administered FFQ. Fruits and vegetables, botanical groups and high-nutrient groups were evaluated. These three classification schemes were compared with plasma carotenoid and vitamin C concentrations from blood samples collected within 1 week of questionnaire completion.
Setting: Shanghai, China.
Subjects: Participants (*n* 2031) comprised women who had participated in a case–control study of diet and breast-related diseases nested within a randomized trial of breast self-examination among textile workers (*n* 266 064)
Results: Fruit intake was significantly ($P < 0.05$) and positively associated with plasma concentrations of α-tocopherol, β-cryptoxanthin, lycopene, α-carotene, β-carotene, retinyl palmitate and vitamin C. Fruit intake was inversely associated with γ-tocopherol and lutein + zeaxanthin concentrations. Vegetable consumption was significantly and positively associated with γ-tocopherol and β-cryptoxanthin concentrations. Each botanical and high-nutrient group was also significantly associated with particular plasma nutrient concentrations. Fruit and vegetable intakes and most plasma nutrient concentrations were significantly associated with season of interview.
Conclusions: These results suggest that the manner in which fruits and vegetables are grouped leads to different plasma nutrient exposure information, which may be an important consideration when testing and generating hypotheses regarding disease risk in relation to diet. Interview season should be considered when evaluating the associations of reported intake and plasma nutrients with disease outcomes.

Higher consumption of fruit and vegetables has been associated with lower risk of several diseases, including heart disease and several cancers[1–4]. Fruits and vegetables contain numerous phytochemicals that may reduce disease risk. High fruit and vegetable intakes may also be a marker for an overall diet or for other lifestyle factors associated with reduced disease risk. Observations regarding disease risk in relation to broad and heterogeneous categories, such as 'fruits' and 'vegetables', have direct implications for public health recommendations, such as 'two cups of fruit and $2\frac{1}{2}$ cups of vegetables per day are recommended for a reference 2000-energy intake'

according to the US Department of Agriculture Dietary Guidelines for Americans 2005[5]. Evaluation of fruits and vegetables classified on the basis of their nutrient content, such as on the basis of particular vitamins or other phytochemicals, is useful for generating hypotheses regarding the biological mechanisms of associations of fruit and vegetable intakes with disease risk.

Many studies on the association between fruit and vegetable intakes and disease risk have been conducted in Western populations; however, fewer data are available on other population groups. The amount and patterns of fruit and vegetable consumption may differ across

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populations. For example, fruit and vegetable intakes in South-East Asia are lower than those of Western populations[6]. A difference in the amount or pattern of consumption may affect the validity and interpretation of dietary intake data.

Our primary objective was to evaluate the validity of fruit and vegetable intakes obtained from an FFQ by evaluating various classification schemes in relation to plasma carotenoid and vitamin C concentrations. Additional analyses were conducted to evaluate dietary intake and plasma concentrations in relation to season of interview and year of interview to evaluate potential bias that might be introduced by these variables.

Experimental methods

Participants and study procedures

Participants (*n* 2031) comprised women who had participated in a case–control study of diet and breast-related diseases nested within a randomized trial of breast self-examination among textile workers in Shanghai, China (*n* 266 064; Fig. 1)[7]. Figure 1 illustrates the selection of participants for the analysis conducted for the present study from the larger randomized trial. Recruitment into the trial took place between 1989 and 1991, and follow-up for breast-related diseases continued through July 2000. Women born between 1925 and 1958 were eligible for participation in the trial (aged 30–64 years at enrolment). Further details regarding eligibility for the randomized trial and baseline data collection are published elsewhere[8]. Dietary data were collected from selected women in the cohort with benign or malignant breast disease diagnosed between 1 September 1995 and 31 July 2000 and from women without breast diseases who were randomly selected from the trial cohort as controls[9]. Controls were frequency-matched to cases on the basis of age. Women with breast-related diseases were eligible as cases for the case–control study if they were diagnosed at one of the three hospitals serving the Shanghai Textile Industry Bureau (STIB). Non-fasting blood samples were collected for the analysis of several nutrients, including carotenoids and vitamin C. Attempts were made to schedule the diet interview and blood sample collection on or before the date of the scheduled breast biopsy for women with benign or malignant breast disease. Women were excluded from the present analysis if their blood sample collection was completed and their FFQ was
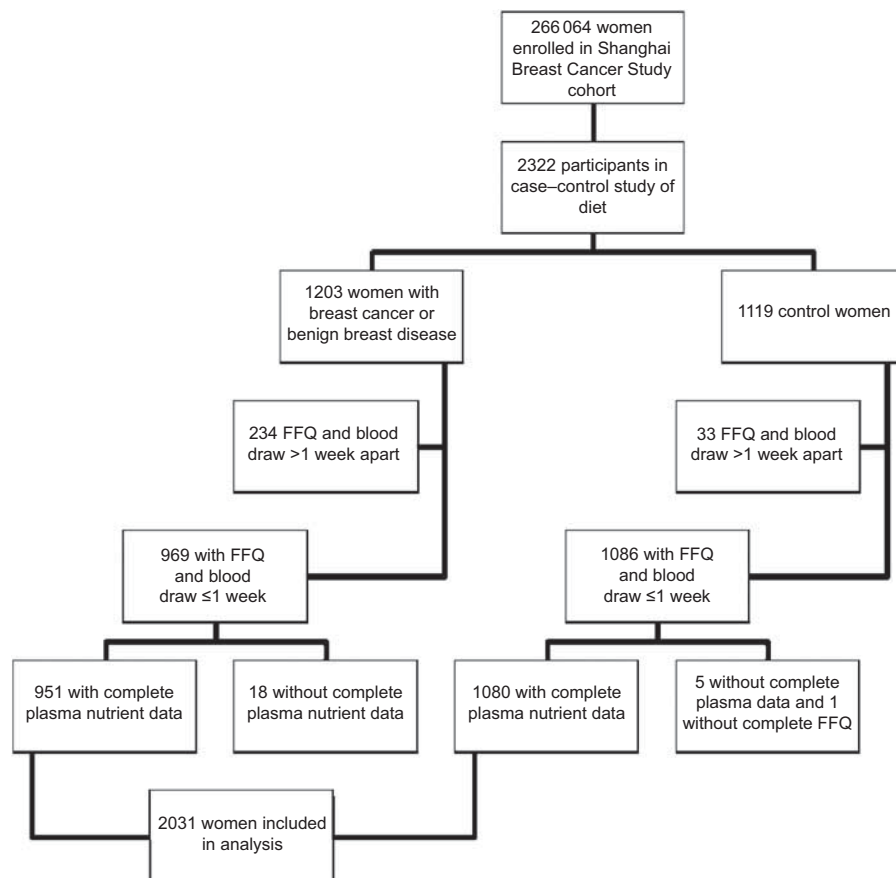

Fig. 1 Female Shanghai textile workers enrolled in a randomized trial of breast self-examination who participated in a nested dietary study

administered >1 week apart or if plasma vitamin C or any of the plasma carotenoids were missing. The Institutional Review Boards at the Fred Hutchinson Cancer Research Center and STIB approved the study, and informed consent from all participants was obtained before their participation.

FFQ and classification of food groups

The FFQ consisted of 107 food items and was administered during an in-person interview. Women were asked 'During most of your adult life how often did you usually eat?' for each of the FFQ food items. Women responded by citing the number of times per day, week, month or year, or they indicated that they had never consumed the item. Foods were classified using a three-grouping system: the traditional group, the botanical group and the high-nutrient group (containing foods high in the nutrient). The botanical groups were included because certain phyto-chemicals may aggregate within the botanical groups distinct from the high-nutrient groups. The traditional groups were mutually exclusive and consisted of fruit, vegetables, red meat, poultry, seafood, eggs, milk and milk products, soya foods, legumes excluding soya and grains excluding corn. Fruits included apples, pears, oranges/tangerines, lychee, bananas, peaches, persimmon, pineapple, grapes, apricots and watermelon. Vegetables included salted mustard greens, other salted vegetables, bok choy, spinach, cabbage, Chinese cabbage, watercress, broccoli, Chinese broccoli, green asparagus, cauliflower, celery, eggplant, wild rice stem, winter squash, lettuce, yellow sweet potatoes or yam, other potatoes, wax gourd, gherkins, carrots, pumpkin, mushrooms, red or green pepper, tomatoes, bamboo shoots, radish/turnip, lotus rhizomes, taro root, corn, onions and chives, garlic stalk and seaweed. Table 1 provides examples of foods included in each botanical group. Foods included in the botanical and high-nutrient groups have been published in detail elsewhere[10]. The high-nutrient groups were not mutually exclusive with respect to included foods, and included groups for high α-carotene (carrots, pumpkin, string beans, winter squash), high β-carotene (apricots, bok choy, broccoli, carrots, Chinese broccoli, Chinese cabbage, persimmon, pumpkin, salted mustard greens, spinach, string beans, watercress, winter squash, yellow sweet potato or yam), high β-cryptoxanthin (corn, oranges/tangerines, persimmon, watermelon), high lutein +zeaxanthin (broccoli, Chinese broccoli, corn, hyacinth beans, salted mustard greens, seaweed, spinach, watercress), high lycopene (persimmon, tomatoes, watermelon) and high total carotenoids (apricots, bok choy, broccoli, carrots, Chinese broccoli, Chinese cabbage, persimmon, pumpkin, salted mustard greens, red or green peppers, seaweed, spinach, tomato, watercress, watermelon, yellow sweet potato or yam).

Table 1 Summary statistics for intakes of fruit and vegetables in 2031 Chinese women in Shanghai (1995–2001)

Dietary intake (servings/week)	Mean	SD	Range	25th percentile	Median	75th percentile	Kurtosis	Skewness
Fruit*	6·4	3·7	0–60	3·8	5·7	8·2	2·43	25·8
Vegetables†	15·7	6·8	3–56	10·8	14·8	19·5	1·01	4·87
Unsalted vegetables	14·6	6·6	2–49	9·7	13·6	18·4	1·01	4·70
Salted and cured vegetables	1·4	2·2	0–18	0·3	0·6	2·0	2·32	9·66
Araceae (e.g. taro root)	0·1	0·4	0–7	0·06	0·1	0·3	7·27	122
Bromeliaceae (e.g. pineapple)	0·0	0·2	0–3	0·04	0·06	0·08	5·95	63·2
Chenopodiaeceae (e.g. spinach)	0·3	0·6	0–14	0·1	0·3	0·6	14·1	389
Compositae (e.g. lettuce)	0·8	1·3	0–8	0·2	0·4	1·1	3·05	13·7
Convolvulaceae/dioscoreaeceae (e.g. yellow sweet potato)	0·0	0·2	0–4	0·02	0·06	0·08	8·29	122
Cruciferae (e.g. bok choy)	5·0	2·8	0–36	3·0	4·6	6·8	1·89	14·6
Cucurbitaceae (e.g. squash)	3·7	1·6	0–14	2·7	3·5	4·6	1·23	7·01
Ebenaceae (e.g. persimmon)	0·1	0·3	0–4	0·04	0·06	0·2	4·58	34·8
Graminae (e.g. bamboo shoots)	0·6	0·7	0–8	0·3	0·5	0·9	3·21	26·1
Laminariaeceae (e.g. seaweed)	0·2	0·4	0–4	0·04	0·2	0·3	3·76	25·3
Liliaceae (e.g. onions)	3·4	3·5	0–30	0·5	2·1	7·0	1·28	6·10
Musaceae (e.g. bananas)	0·7	1·0	0–7	0·2	0·5	1·2	3·24	18·0
Nymphaeaceae (e.g. lotus rhizomes)	0·0	0·2	0–2	0·04	0·08	0·1	5·05	52·2
Rosaceae (e.g. apples)	2·5	2·3	0–51	1·0	2·0	3·6	5·37	98·2
Rutaceae (e.g. oranges)	0·9	0·9	0–7	0·25	0·67	1·2	2·10	11·2
Sapindaceae (e.g. litchis)	0·0	0·2	0–2	0·04	0·06	0·08	6·73	69·0
Solanaceae (e.g. peppers)	2·7	1·9	0–23	1·5	2·3	3·4	2·32	14·6
Umbelliferae (e.g. celery)	0·6	0·9	0–9	0·3	0·4	0·8	4·37	33·9
Vitaceae (e.g. grapes)	0·3	0·6	0–4	0·08	0·2	0·6	2·43	10·1
High β-carotene	6·3	3·2	0–37	4·0	5·8	8·2	1·79	12·6
High lutein + zeathanin	1·3	1·1	0–18	0·67	1·0	1·6	4·36	46·6
High lycopene	2·9	1·3	0–21	2·2	2·8	3·6	2·44	26·9
High α-carotene	1·7	1·1	0–11	0·94	1·5	2·2	2·13	12·3
High β-cryptoxanthin	2·8	1·4	0–15	2·0	2·6	3·5	1·75	11·9
High total carotenoid	8·5	3·7	0–40	5·9	8·0	11·0	1·64	10·3

*Fruits included: apples, apricots, bananas, grapes, lychee, oranges or tangerines, peaches, pears, persimmon, pineapple and watermelon.
†Vegetables included: unsalted vegetables (asparagus, bok choy, broccoli, cabbage, Chinese broccoli, Chinese cabbage, spinach and watercress) and salted and cured vegetables (fermented bean curd, salted mustard greens and other salted vegetables).

The botanical groups were mutually exclusive with respect to included foods and included araliaceae (fresh ginseng, white ginseng powder or extract, red ginseng powder or extract), compositae (sunflower seeds, lettuce), convolvulaceae/dioscoreaceae (yellow sweet potatoes, yam), cruciferae (bok choy broccoli, cabbage, cabbage, cauliflower, Chinese broccoli, Chinese cabbage, radish or turnip, watercress), cucurbitaceae (gherkin, pumpkin, watermelon, wax gourd, winter squash), ebenaceae (persimmon), laminariaceae (seaweed), leguminosae (fresh fava beans, fried bean curd, fried bean curd puff, green or kidney beans, hyacinth beans, mung bean sprouts, mung beans, other dried beans, other soyabean foods, pea or cow peas, peanuts, peanut butter, red pea or green bean groups, soyabean milk, soyabeans, string beans, szuki beans), liliaceae (asparagus, Chinese chives, chives, garlic, garlic stalk, onions, scallions), rosaceae (apples, apricots, peaches, pears), rutaceae (oranges, tangerines), sapindaceae (lychee), solanceae (eggplant, hot pepper, other potato, red or green pepper, tomato), umbelliferae (carrots, celery), vitaceae (grapes) and zingiberaceae (ginger root). Servings per week were calculated for each food group. The average serving size obtained from the Chinese population was used to estimate a serving from the reported frequency for each food item. Each reported frequency was assigned the average serving size for that food item. Average serving sizes were obtained from the 1992 China Health and Nutrition Survey[11].

Plasma collection and nutrient analysis

Blood samples were collected into foil-covered EDTA 10 ml vacutainers and centrifuged within 45 min of collection or refrigerated and centrifuged within 2 h of collection. The samples were centrifuged for 15 min at 1300**g**. Plasma was transferred into 2 ml cryovials and frozen at $-20°C$ for 1 month or at $-70°C$ for longer periods until they were shipped to Seattle. Specimens were shipped to Seattle on dry ice and immediately stored at $-70°C$.

Ascorbic acid concentration measurements have been described in detail elsewhere[12]. The intra-assay per cent CV (%CV) was 6·3 and 1·3 at 0·83 and 1·65 mg/dl, respectively. The inter-assay %CV was 8·1 and 5·0 at 0·78 and 1·65 mg/dl, respectively. The extraction of analytes from plasma, the quality control parameters and the HPLC methods for measurements of plasma carotenoids and tocopherols have been published previously[13,14]. The HPLC method in the present study included a profile of carotenoids, carotenes, retinols and tocopherols in a single HPLC run and has been described elsewhere[12]. The %CV for the pooled quality control samples for all analytes was ≤10 %.

Statistical methods

Mean and SD were calculated as summary statistics. Because distributions were not normally distributed, data were log transformed before analyses for plasma concentrations of β-cryptoxanthin, lycopene, α-carotene, β-carotene, retinyl palmitate and vitamin C. Exponentiations of the mean value of the log-transformed nutrients to obtain the geometric mean were performed for presenting the data in the results. Dietary intake was divided into quartiles for analysis. Linear regression was also used to evaluate differences in mean plasma nutrient concentrations across quartiles of intake, adjusted for each woman's age, case–control classification, season of interview and year of interview. The quartile of intake was calculated using the median and 25th and 75th percentiles of each food group (Table 1) and was included as a single categorical term in the linear regression models. Season was defined as four 3-month categories (December–February, March–May, June–August and September–November). Year of recruitment was divided into three categories: 1995–1996, 1997–1998 and 1999–2001. Case–control classification was divided into three groups: controls, women with benign breast disease and women with breast cancer. In order to quantify the differences across seasons and year of interview, dietary intake and plasma nutrients were evaluated in relation to season of interview and year of interview using ANOVA and regression analyses, respectively, adjusted for each woman's age, case–control classification and, for dietary nutrients, total energy (kJ) intake. Analyses using controls only were evaluated, and differences in overall interpretation of the results were unremarkable; therefore, the results of analyses for all participants are presented. A sampling of plots of predicted values compared with standardized residuals was evaluated for heteroscedasticity; plots were consistent with meeting the assumptions of homoscedasicity. Statistical significance was considered at $P < 0·05$. Analyses were conducted using the STATA statistical software package version 11·0 (StataCorp., College Station, TX, USA).

Results

Women reported consuming an average of approximately six servings of fruit and sixteen servings of vegetables per week (Table 1). Fresh vegetables contributed to the majority of vegetable intake. The correlation between fruit and vegetable intakes was $r = 0·39$. Cruciferae, cucurbitaceae, liliaceae, rosaceae and solanaceae were the most frequently consumed fruit and vegetable botanical groups. High β-carotene, total carotenoid, lycopene and β-cryptoxanthin foods were the most frequently consumed high-nutrient groups. Weekly servings of high β-carotene and high total carotenoid foods were highly correlated ($r = 0·91$); therefore, further analyses were conducted with high total carotenoid foods only. Although similar foods were in the high lycopene and high β-cryptoxanthin groups, weekly servings of these foods were not strongly correlated enough to be considered collinear ($r = 0·58$).

Table 2 Summary statistics for plasma nutrient concentrations in 2031 Chinese women in Shanghai (1995–2001)

Plasma nutrient concentrations	Mean	SD	Range	Kurtosis	Skewness
β-Carotene (μg/dl)	31·8	21·9	3·00–399	71·60	5·64
α-Carotene (μg/dl)	2·62	2·06	0·60–42·9	121	8·48
Lycopene (μg/dl)	7·40	7·20	0·80–78·1	11·7	2·42
β-Cryptoxanthin (μg/dl)	14·0	14·1	1·40–160	2·95	0·02
Lutein + zeaxanthin (μg/dl)	37·0	16·5	7·90–184	11·1	1·91
Retinol (μg/dl)	41·5	11·2	6·70–107	5·36	0·96
Retinyl palmitate (μg/dl)	3·60	2·78	0·40–85·5	414	16·5
α-Tocopherol (μg/ml)	9·28	3·12	0·10–35·8	12·3	2·34
γ-Tocopherol (μg/ml)	2·14	0·99	0·30–9·35	8·05	1·91
Vitamin C (μg/ml)	8·12	8·37	<LOQ–12·1	68·8	6·61

LOQ, limit of quantitation.

The distribution of plasma nutrients is presented in Table 2. Wide variation in the plasma concentrations of nutrients was observed among the women.

Fruit intake was significantly and positively associated with plasma concentrations of α-tocopherol, β-cryptoxanthin, retinyl palmitate, lycopene, α-carotene, β-carotene and vitamin C (Table 3). Inverse associations of γ-tocopherol and lutein + zeaxanthin with fruit intake were observed. Vegetable consumption was significantly and positively associated with γ-tocopherol and β-cryptoxanthin. The botanical and high-nutrient groups were associated with plasma nutrients in a manner distinct from association with the fruit and vegetable groups. Almost all groups were positively associated with vitamin C concentrations. Some groups (e.g. rosaceae) were associated with most nutrient concentrations, whereas other groups (e.g. solanceae) were associated with only a few nutrient concentrations.

Season and year of interview were significantly associated with diet and most plasma nutrients (Table 4). Women reported lower lifetime fruit consumption when interviewed during the summer and autumn months and lower vegetable consumption when interviewed during the autumn months. Fruit and vegetable intakes and mean plasma concentrations of lutein + zeaxanthin, γ-tocopherol and β-cryptoxanthin decreased over the course of the study. To evaluate whether decreased fruit and vegetable consumption over time was balanced by increased consumption of other foods, we examined the mean intake of other main food groups in relation to year of interview, adjusted for total enegy (kJ), case–control classification, season of interview and age at interview. Consumption of red meat (mean intake for 1995–1996, 1997–1998 and 1999–2001 was 5·6, 5·3 and 4·8 servings/week, respectively) and legumes excluding soya (3·5, 3·2 and 2·9 servings/week for the respective corresponding time periods) also decreased significantly in relation to year of interview ($P \leq 0.001$). Consumption of poultry (0·8, 1·0 and 1·0 servings/week), eggs (3·2, 3·2 and 3·7 servings/week), milk and milk products (3·2, 3·1 and 4·1 servings/week) and grains excluding corn (5·5, 5·2 and 6·9 servings/week) increased significantly ($P \leq 0.001$).

No change in consumption of seafood (3·4, 3·3 and 3·3 servings/week) or soya foods (5·6, 5·2 and 5·4 servings/week) was observed ($P > 0.3$).

Discussion

Serum and plasma carotenoids and vitamin C are proposed as biomarkers of fruit and vegetable intakes[15–17]. Carotenoids are stored in the liver and blood concentrations provide a marker of long-term exposure. Blood concentration of vitamin C, which is not stored, serves as a short-term marker of exposure[18]. In the present study, we observed that fruit intake was associated with most plasma carotenoids and vitamin C. Inverse associations of γ-tocopherol and lutein + zeaxanthin with fruit intake were observed; it is remarkable that there was no positive association because γ-tocopherol is found in high amounts in vegetable oils and lutein + zeaxanthin is found in eggs and corn, as well as in green and yellow fruits and vegetables. However, the inverse association may have been observed by chance or may reflect a higher consumption of other foods, such as vegetables, that replaces fruit consumption. Vegetable intake was associated with two of the ten plasma nutrients evaluated, β-cryptoxanthin and γ-tocopherol. These observations suggest that the fruit group provides a broad classification of exposure to carotenoids and that the vegetable group provides an index of exposure for select nutrients.

We observed that the high total carotenoid group was positively associated with plasma concentrations of α-carotene, β-cryptoxanthin, lutein + zeathanin, γ-tocopherol and vitamin C. This pattern was distinct from the high lycopene and high β-cryptoxanthin food groups. Among other plasma nutrients, the high lycopene group was positively associated with plasma lycopene concentrations and the high β-cryptoxanthin group was positively associated with plasma β-cryptoxanthin concentrations. These observations suggest that the high total carotenoid group provides a valid assessment of several plasma carotenoids and that the specific carotenoid food groups adequately reflect their specific plasma nutrients.

Table 3 Mean* plasma nutrients in 2031 Chinese women in Shanghai (1995–2001) in relation to quartiles of fruit and vegetable intakes, adjusted for age at interview, year and season of interview and case–control classification

Food groups (servings/week)	β-Carotene (µg/dl)	α-Carotene (µg/dl)	Lycopene (µg/dl)	β-Cryptoxanthin (µg/dl)	Lutein + zeaxanthin (µg/ml)	Retinol (µg/dl)	Retinyl palmitate (µg/dl)	α-Tocopherol (µg/ml)	γ-Tocopherol (µg/ml)	Vitamin C (µg/ml)
Fruit										
Q1	25·8	2·12	4·88	8·34	37·9	40·9	3·20	9·04	2·20	7·65
Q2	26·7	2·23	5·13	9·33	37·3	41·3	3·25	9·20	2·16	8·03
Q3	27·7	2·35	5·40	10·4	36·7	41·7	3·31	9·36	2·12	8·40
Q4	28·7	2·47	5·68	11·7	36·0	42·1	3·36	9·53	2·08	8·81
P for trend	0·002	<0·001	<0·001	<0·001	0·049	0·084	0·034	0·009	0·037	<0·001
Vegetables										
Q1	27·1	2·26	5·20	9·44	36·8	41·1	3·31	9·20	2·08	7·97
Q2	27·2	2·28	5·24	9·72	36·9	41·4	3·29	9·26	2·12	8·13
Q3	27·3	2·30	5·29	10·0	37·0	41·6	3·27	9·31	2·16	8·30
Q4	27·3	2·33	5·33	10·3	37·1	41·9	3·24	9·37	2·20	8·47
P for trend	0·790	0·255	0·520	0·046	0·724	0·216	0·371	0·360	0·039	0·091
Cruciferae										
Q1	25·8	2·26	5·40	9·51	35·5	41·6	3·22	9·19	2·06	7·58
Q2	26·7	2·28	5·31	9·74	36·5	41·5	3·26	9·25	2·12	7·99
Q3	27·7	2·30	5·22	9·98	37·5	41·5	3·29	9·31	2·17	8·44
Q4	28·7	2·33	5·12	10·2	38·4	41·5	3·33	9·38	2·21	8·91
P for trend	0·001	0·260	0·178	0·098	0·003	0·903	0·156	0·312	0·012	<0·001
Cucurbitaceae										
Q1	25·9	2·22	5·10	9·23	36·9	41·1	3·26	9·13	2·16	7·57
Q2	26·8	2·27	5·21	9·65	37·0	41·4	3·27	9·23	2·15	7·99
Q3	27·7	2·32	5·32	10·1	37·0	41·7	3·28	9·34	2·14	8·44
Q4	28·6	2·36	5·43	10·5	37·0	42·0	3·30	9·44	2·13	8·92
P for trend	0·003	0·036	0·111	0·003	0·965	0·165	0·616	0·093	0·595	<0·001
Liliaceae										
Q1	28·1	2·32	5·19	10·3	38·3	40·8	3·32	9·29	2·06	8·50
Q2	27·5	2·30	5·24	10·0	37·4	41·3	3·29	9·29	2·11	8·31
Q3	26·9	2·28	5·29	9·72	36·5	41·8	3·26	9·28	2·17	8·11
Q4	26·4	2·27	5·34	9·45	35·6	42·2	3·23	9·27	2·23	7·93
P for trend	0·080	0·486	0·453	0·066	0·005	0·035	0·282	0·913	0·005	0·065
Rosaceae										
Q1	25·8	2·21	5·00	8·78	37·4	41·1	3·20	9·13	2·20	7·73
Q2	26·7	2·26	5·18	9·49	37·1	41·4	3·25	9·23	2·16	8·05
Q3	27·7	2·32	5·35	10·3	36·8	41·6	3·30	9·34	2·12	8·39
Q4	28·8	2·37	5·54	11·1	36·6	41·9	3·36	9·44	2·10	8·74
P for trend	0·001	0·013	0·008	<0·001	0·382	0·247	0·038	0·086	0·044	0·001
Solanaceae										
Q1	27·2	2·26	5·06	9·48	36·9	41·6	3·31	9·34	2·11	7·92
Q2	27·2	2·28	5·20	9·73	37·0	41·6	3·29	9·30	2·13	8·11
Q3	27·2	2·30	5·33	10·0	37·0	41·5	3·27	9·26	2·15	8·32
Q4	27·2	2·33	5·48	10·3	37·0	41·4	3·24	9·23	2·17	8·52
P for trend	0·980	0·280	0·042	0·072	0·962	0·704	0·378	0·516	0·334	0·043
High total carotenoid fruit and vegetables										
Q1	26·4	2·22	5·34	9·38	36·0	41·4	3·26	9·20	2·07	7·65
Q2	27·0	2·27	5·29	9·70	36·6	41·5	3·27	9·26	2·12	8·02
Q3	27·5	2·32	5·24	10·0	37·3	41·5	3·28	9·31	2·16	8·41
Q4	28·1	2·36	5·20	10·4	38·0	41·6	3·29	9·37	2·21	8·83
P for trend	0·072	0·035	0·491	0·025	0·038	0·738	0·636	0·365	0·016	<0·001

Table 3 Continued

Food groups (servings/week)	β-Carotene (μg/dl)	α-Carotene (μg/dl)	Lycopene (μg/dl)	β-Cryptoxanthin (μg/dl)	Lutein + zeaxanthin (μg/ml)	Retinol (μg/dl)	Retinyl palmitate (μg/dl)	α-Tocopherol (μg/ml)	γ-Tocopherol (μg/ml)	Vitamin C (μg/ml)
High lycopene fruits and vegetables										
Q1	26·5	21·6	4·91	8·93	37·8	41·3	3·29	9·14	2·12	7·65
Q2	27·0	2·25	5·14	9·54	37·2	41·4	3·28	9·24	2·13	8·02
Q3	27·5	2·34	5·38	10·2	36·7	41·6	3·27	9·33	2·15	8·41
Q4	27·9	2·43	5·64	10·9	36·1	41·7	3·26	9·43	2·16	8·82
P for trend	0·136	<0·001	<0·001	<0·001	0·088	0·473	0·719	0·119	0·520	<0·001
High β-cryptoxanthin fruit and vegetables										
Q1	26·9	2·15	4·77	7·81	39·0	41·1	3·23	9·08	2·17	7·76
Q2	27·1	2·24	5·06	9·00	37·8	41·3	3·26	9·20	2·15	8·03
Q3	27·3	2·32	5·37	10·4	36·5	41·6	3·29	9·33	2·14	8·31
Q4	27·5	2·41	5·70	11·9	35·2	41·9	3·31	9·45	2·12	8·60
P for trend	0·580	<0·001	<0·001	<0·001	0·001	0·248	0·336	0·065	0·461	0·013

*Geometric means for β-cryptoxanthin, lycopene, α-carotene, β-carotene, retinyl palmitate and vitamin C.

A strength of using these high-nutrient classifications is that, although they are a finer stratification compared with fruit and vegetables, there is adequate variation in intake. A limitation of using these classifications is that it may be more difficult to provide public health recommendations regarding consumption of the high-nutrient groups compared with public health recommendations for increased consumption of fruit and vegetables in general.

Fruits and vegetables can be classified on the basis of their botanical family groups, such as cruciferae, or on the basis of their highly specific phytochemical content, such as isoflavones in soya or glucosinolates in cruciferous vegetables. Evaluating the associations between these groups and disease risk is useful for generating and evaluating hypotheses regarding risk associated with particular phytochemicals found in high amounts in these botanical families. We observed patterns of association distinct from the other classifications with regard to plasma carotenoids for the five categories of botanical groups evaluated. In general, the patterns of association were consistent with what might be expected. For example, cruciferae was positively associated with β-carotene, lutein + zeaxanthin, γ-tocopherol and vitamin C, and solanceae, which includes eggplant and peppers, was positively associated with lycopene and vitamin C. This observation suggests that these groups are useful for evaluating particular botanical families of interest. However, rosaceae (apples, pears, peaches and apricots) was associated with most plasma nutrients, suggesting that this botanical family may be serving as a marker of consumption of other foods.

Season of interview was associated with fruit and vegetable intakes and with plasma nutrient concentrations. Consumption of overall and particular fruits and vegetables is usually seasonal, based on availability and pricing, and therefore changes in plasma nutrients likely reflect changes in consumption. For example, plasma lycopene was higher in summer months and lutein + zeaxanthin was lower in autumn months, which may reflect seasonal changes in consumption of high lycopene foods (e.g. persimmon, tomato and watermelon) or high lutein + zeaxanthin foods (e.g. perishable greens). The FFQ queried participants about their usual intake of particular foods during their adult life. Association of season of interview with fruit and vegetable intakes likely reflects a source of error in dietary exposure measurement, in which participants extrapolate current exposure to lifetime exposure. As a result, season of interview is associated with exposure (diet) and could introduce non-differential or differential bias when evaluating an exposure–outcome association, depending on the relationship of season of interview with outcome[19].

Year of interview was also associated with fruit and vegetable intakes and with plasma nutrient concentrations. Plasma β-cryptoxanthin, γ-tocopherol and vitamin C were associated with vegetable intake. β-Cryptoxanthin

Table 4 Mean* of weekly fruit and vegetable intakes and of plasma nutrients in 2031 Chinese women in Shanghai (1995–2001) in relation to season and year of interview, adjusted for age at interview and case–control classification. Fruit and vegetable intakes were also adjusted for total energy intake

	Season of interview†					Year of interview			
	Winter (*n* 601)	Spring (*n* 600)	Summer (*n* 373)	Autumn (*n* 457)	*P* value‡	1995, 1996 (*n* 442)	1997, 1998 (*n* 494)	1999, 2000, 2001 (*n* 1095)	*P* for trend§
Intake (servings/week)									
Fruit	6·4	6·7	6·0	6·2	<0·001	7·5	7·2	5·5	<0·001
Vegetables	16	16	16	15	0·003	18	17	14	<0·001
Plasma concentrations									
β-Carotene (μg/dl)	31·0	31·1	31·2	28·9	0·132	31·9	28·3	31·1	0·562
α-Carotene (μg/dl)	2·76	2·33	2·36	2·99	<0·001	2·61	2·58	2·62	0·934
Lycopene (μg/dl)	8·97	13·2	26·6	13·3	<0·001	14·4	14·6	14·1	0·542
β-Cryptoxanthin (μg/dl)	19·2	13·4	6·39	11·2	<0·001	14·3	15·6	11·8	<0·001
Lutein + zeaxanthin (μg/dl)	38·9	40·8	35·5	30·6	<0·001	41·5	37·0	35·2	<0·001
Retinol (μg/dl)	40·7	41·4	41·6	42·6	0·044	40·3	42·1	41·7	0·042
Retinyl palmitate (μg/dl)	3·55	3·53	3·75	3·50	0·433	3·70	3·53	3·53	0·306
α-Tocopherol (μg/ml)	9·35	9·17	9·05	9·54	0·081	9·18	9·04	9·44	0·162
γ-Tocopherol (μg/ml)	2·14	2·19	2·17	2·06	0·188	2·22	2·18	2·09	0·037
Vitamin C (μg/ml)	7·92	7·41	6·68	6·19	<0·001	7·56	5·90	7·56	0·902

*Geometric means for β-cryptoxanthin, lycopene, α-carotene, β-carotene, retinyl palmitate and vitamin C.
†Winter: December, January and February; Spring: March, April and May; Summer: June, July and August; Autumn: September, October and November.
‡*P* value for difference between categories calculated from ANOVA.
§*P* value for linear trend across categories calculated from linear regression.

and γ-tocopherol, which are stored in the liver and reflect a longer period of exposure, were also inversely associated with year of interview, whereas vitamin C, which reflects a shorter exposure period, was not associated. Red meat and legume consumption also decreased over the course of the study, whereas consumption of poultry, milk and milk products and grain increased. Overall, these observations suggest that the reported decreased fruit and vegetable intakes may represent a real trend of changing consumption patterns. There are many possible reasons for a decrease in fruit and vegetable consumption with time, including increased urbanization, although this has not been predicted to have a remarkable influence on China's vegetable and fruit consumption[20], and changing availability and cost of fruits and vegetables in response to shifts in import and export practices during 1999–2001[21]. However, it is also possible that the lower fruit and vegetable consumption in later years was observed by chance.

The present study has several potential limitations. One limitation is that the average serving size for the population was used to calculate dietary intake for all participants. Willett summarized results from several studies that indicated that individuals were relatively inaccurate in recalling portion sizes and that the majority of intake variability was from frequency of consumption rather than from serving size[19]. Thus, not collecting serving size information likely reduced the intake values but did not markedly alter the overall ranking of individuals by intake. This could be expected to be a minor source of bias across quartiles of intake. However, if a reduction did occur in the variability in dietary intake, this would represent a source of non-differential bias and would have reduced the ability to detect an association between

dietary intake and plasma nutrient concentrations. In this circumstance, our results would be conservative. Because a single plasma sample, rather than multiple samples, was collected over time and the single plasma sample was compared with usual adult intake, we expect a decreased ability to detect an association. Overall, these sources of potential non-differential bias in our study suggest that the observed associations between plasma nutrients and dietary fruit and vegetable intakes may be conservative.

Our primary objective was to evaluate the validity of fruit and vegetable intakes obtained from an FFQ by evaluating various classification schemes in relation to plasma carotenoid and vitamin C concentrations. From this evaluation, we observed several outcomes relevant to the study design and analysis. First, various classifications of fruit and vegetable intakes were associated with plasma carotenoids and vitamin C, suggesting that intakes estimated from the FFQ provide a valid assessment of exposure. Second, the fruit and vegetable, high-nutrient and botanical groups were distinctly associated with plasma nutrients. Third, season of interview should be considered as a potential confounder, or cases and controls should be matched to season of interview. We also observed a significant decrease in fruit and vegetable consumption over time in this population of Chinese women and, given the positive associations of fruit and vegetable intakes with health, this should be evaluated in additional studies.

Acknowledgements

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