Original Article

Validity of single vs. multiple FFQs in ranking nutrient intake among Japanese adults: the Tohoku Medical Megabank Project

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Background and Objectives: Repeating food frequency questionnaires (FFQs) within the same population was reported to improve the validity of correlation coefficient (CC). However, the enhancement of validity in ranking agreement remains underreported. Herein, we assessed the validity of energy and nutrient intake estimates using single and multiple FFQs and their ability to rank individuals. **Methods and Study Design:** 213 men and women aged ≥20 years were recruited from the residents participating in the Tohoku Medical Megabank Project (TMM) cohort studies; three FFQs were conducted in November each year from 2019 to 2021, with 12-day weighted food records (WFRs) as the reference method. Spearman's rank CCs were calculated between single or multiple FFQs estimates and those obtained through the 12-day WFR. Additionally, the ranking agreement was compared based on cross-classification. **Results:** CCs between intake estimated using a single FFQ and 12-day WFR were moderate for several nutrients, with median CCs of 0.52 for men and 0.48 for women. CCs for multiple FFQs were slightly higher than that of single FFQ, with median CCs of 0.59 for men and 0.56 for women. Regardless of the number of FFQs, the proportion of subjects classified into the opposite extreme category was ≤5% for most nutrients. **Conclusions:** A single FFQ used for adults in the TMM cohort studies showed moderate validity. Estimates from multiple FFQs improved the accuracy slightly; nevertheless, this indicates that relying on a single FFQ is unlikely to result in a serious misclassification compared to using intake data from multiple FFQs over a relatively short period.

Key Words: dietary assessment, Food Frequency questionnaire, FFQ, validity

INTRODUCTION

Food frequency questionnaires (FFQ) accuracy is noted to be validated for use in populations.[1] Herein, the FFQ was developed and validated for use in a Japan Public Health Center-based prospective study (JPHC),[2-7] and was revised for general use and external validation among urban cancer screenees.[8] Moreover, the option "constitutionally unable to eat" was added to intake frequency for genetic and nutritional epidemiology studies, considering

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individual constitution. As the impact of these significant question option revisions on its validity remained uncertain, we assessed its validity for adult residents participating in the Tohoku Medical Megabank Project (TMM) studies.[9]

Furthermore, the validity of the repeated administration of FFQs has rarely been examined,[10, 11] and both were reported to improve the correlation coefficient (CC) in their validity. However, none of them confirmed the improvement in the ability to rank subjects by dietary intake, which is highly used in cohort studies.

This study primarily aimed to test the validity of FFQs used for adult men and women in TMM cohort studies by comparing nutrient intake estimates using FFQs with those from 12-day weighted food records (WFR). We also aimed to determine the accuracy of the estimates from single and multiple FFQs and to evaluate these correlations in aspects of ranking subjects by dietary intake.

METHODS

Study setting and participants

The study was conducted in three areas specified in the large-scale epidemiological genomic and omics research organized by Tohoku University Tohoku Medical Megabank Organization (ToMMo).[9] Seven community support centers were established in Miyagi Prefecture for a voluntary admission-type recruitment and health assessment of participants, consisting of the TMM community-based cohort study (TMM CommCohort Study),[12] TMM birth and three-generation cohort study (TMM BirThree Cohort Study).[13] Participants were recruited based on the following eligibility criteria: Miyagi Prefecture residents aged 20 years or over and can visit either Sendai, Iwanuma, or Ishinomaki community support centers. Through recruitment in a cohort-study office, 228 men and women agreed to participate in this study, including both participants and non-participants of the TMM CommCohort Study[12] and TMM BirThree Cohort Study.[13] Among them, 89 men and 124 women who completed the survey were included for validity and reproducibility analysis. As an incentive to participate, participants received a reward and the report of their results regarding energy and nutrition consumption, based on 12-day dietary records, after the survey was completed. This study was approved by the Tohoku University Tohoku Medical Megabank Organization Ethics Committee, the Nara Women's University Ethics Review Committee on Research Involving Human Subjects, and all other collaborating research institutions. All participants provided a written informed consent to participate.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures were approved by the Ethics Committee of Tohoku University Tohoku Medical Megabank Organization [No. 2019-4-057] and all other collaborating research institutions, including Nara Women's University [No. 19-02]. Written informed consent was obtained from all subjects.

Data collection

Between November 2019 and August 2021, intake data were obtained from participants using the three-consecutive-day WFR (12-day WFR) over four seasons as the reference method. This was due to the postponement of WFR interviews scheduled for the spring and summer of 2020 because of COVID-19. A self-administered FFQ was conducted three times (FFQ1, FFQ2, and FFQ3) at a one-year interval (Figure 1). Information on height, weight, smoking, and drinking habits was collected through a self-report questionnaire integrated with each FFQ. To determine the validity of FFQs covering the past year's diet, we used information from FFQ3, which was conducted after completing all WFRs. The analysis included 213 participants (89 men and 124 women) who completed up to the third FFQ and 12-day WFR. The 15 participants excluded from the study did not complete both the three FFQs and the 12-day WFR, which were conducted over a 2-year period.

Reference methods

The 12-day WFR consisted of two weekdays and one weekend day for each of the four seasons. The participants used digital cooking scales (Tanita Co. Ltd, Tokyo, Japan), measuring cups, and measuring spoons to record the weight of ingredients before cooking at home. For restaurant meals and side dishes, the weight and approximate amount of food were recorded as specifically as possible. Food records were reviewed for any omissions and coded for food type and weight during interviews conducted by standardized, trained surveyors on the day following the survey's completion in their respective areas of implementation.[14] The average energy and nutrient intakes over the 12 days were used as reference values for each individual's habitual intake.

FFQ

The FFQs included 139 food and beverage items and 10 frequency categories, spanning from "almost never" to "≥7 times per day" (or "≥10 glasses per day" for beverages) and "constitutionally unable to eat." It inquired about the usual consumption of listed foods over the past year.

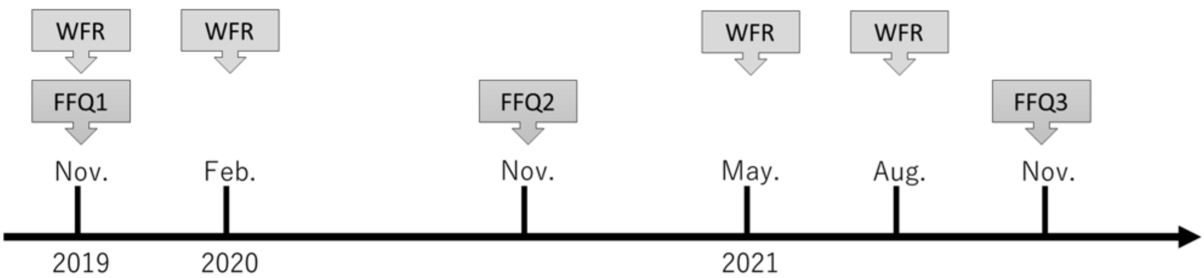

Figure 1. Data collection sequence. WFR, consecutive three-day weighted food record; FFQ, food frequency questionnaire

Portion sizes were specified for each food item, with three standard options: medium (standard), small (50% smaller), and large (50% larger). The food list was based on the FFQ used in the JPHC study, which was validated in Japanese adult men and women.[2-6] Additionally, the FFQ had some revisions in food list, and external validation was done on urban cancer screenees.[8] Following revisions were further made for using TMM cohort studies: addition of a frequency category of "constitutionally unable to eat". In this study, to examine the validity of such modified FFQs in the cohort, they were administered three times over the 2-year period. The percentage of people who selected 'constitutionally unable to eat' for each item is listed in the previous report on the validity of food group intake.[15] Missing responses were checked by a study staff and filled in by participants (in person or by mail). The intake of energy and 48 nutrients was calculated using the Standard Tables of Food Composition in Japan 2010,[16] Standard Tables of Food Composition in Japan Fifth Revised and Enlarged Edition 2005 For Fatty Acids,[17] and a specifically developed food composition table for isoflavones and lycopene.[18, 19]

Statistical analysis

The mean and median intakes of each nutrient, estimated from FFQ1, FFQ2, and FFQ3 as a single FFQ, were compared to the intakes estimated from the 12-day WFR for 89 men and 124 women. Cumulative averages were calculated using FFQ1 and FFQ3 (FFQ1&3), with FFQ1, FFQ2, and FFQ3 (FFQ1&2&3) as the multiple FFQs. These intakes were compared to those obtained from the 12-day WFR. Percentage differences were calculated for each nutrient intake in both single and multiple FFQs compared to the 12-day WFR. Coefficients of variation (CVs, %) were computed for each nutrient by dividing the standard deviation (SD) by the mean intake for each FFQ. To assess the validity of both single and multiple FFQs, Spearman's rank CCs were calculated between the intakes based on FFQs and 12-day WFR, with energy-adjusted values. The median values of the CVs and CCs for energy and 48 energy-adjusted nutrient intakes (compared to the 12-day WFR) were calculated. Energy adjustment was performed using a residual model.[1] The observed CCs were corrected for the attenuating effect of random intra-individual error from the usual intake of each energy and nutrient.[8, 14] To compare the agreement of categorization of estimated intakes based on each FFQ with that of the 12-day WFR, we compared the number of participants classified into the same, adjacent, and extreme categories by cross-classification according to quintile. The weighted kappa statistic was calculated for each nutrient based on their respective quintiles: a coefficient more than 0.80 as a very good agreement, 0.61–0.80 as a good agreement, 0.41–0.60 as a moderate agreement, 0.21–0.40 as a fair agreement, and <0.20 as a poor agreement.[20] To assess the reproducibility of intakes, intraclass correlation coefficients (ICCs) were calculated for energy-adjusted values between FFQ1 and FFQ3, administered at a two-year interval, and between FFQ2 and FFQ3, administered at a one-year interval. To compare the estimates from FFQ3 with other FFQs, we first conducted Friedman's test among the intakes from FFQ1, FFQ2, and FFQ3. Then, Wilcoxon's signed-rank test (vs. FFQ3) was done for post hoc analysis. Bonferroni correction was also applied, considering a statistical significance at $p < 0.001$ (0.05 divided by 49, the number of intakes) for both genders due to the number of exposures. The results of multiple comparisons are not shown in the table. All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Characteristics of participants

The information of subjects who completed the 12-day WFR and three FFQs is shown in Table 1. The mean age was 57.2 years in men and 53.8 years in women at the FFQ3 survey. The mean (SD) body mass index was 24.1 (3.0) in men and 22.7 (3.9) in women. The proportion of current smoker and current drinker was 22.5% and 76.4% among men and 0.8% and 40.3% among women, respectively.

Validity of single and multiple FFQs for intakes

The percentage differences in energy intake based on FFQ3, FFQ1&3, and FFQ1&2&3, compared to the 12-day WFR, were −5.4%, −4.2%, and −4.5%, respectively, in men, and −2.8%, 1.8%, and 2.6%, respectively, in women (Table 2 and 3). Most nutrient intakes based on the FFQs were underestimated compared to those based on the 12-day WFR in men, regardless of the FFQ

Table 1. Characteristics of participants who completed 12d-WFR and three FFQs (FFQ3)

	Men (n=89)		Women (n=124)	
Age (years), mean (SD)	57.2	(16.2)	53.8	(15.5)
Height (cm), mean (SD)	167	(6.5)	157	(5.5)
Weight (kg), mean (SD)	67.7	(9.7)	55.8	(9.9)
BMI (kg/m^2), mean (SD)	24.1	(3.0)	22.7	(3.9)
Smoking status, n (%)				
Current smoker	18	(20.2)	1	(0.8)
Ex-smoker	44	(49.4)	25	(20.2)
Never smoker	27	(30.3)	98	(79.0)
Alcohol drinking, n (%)				
Current drinker	64	(71.9)	50	(40.3)
Abstainer	3	(3.4)	1	(0.8)
Non-drinker	17	(19.1)	58	(46.8)
Constitutionally unable to drink	5	(5.6)	15	(12.1)

12d-WFR, 12-day weighted food record; SD, standard deviation.

Table 2. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in men

(n=89)	12d-WFR				FFQ3					
	Mean	SD	CV	Med	Mean	SD	CV	Med	%†	CC‡
Energy, kcal	2253	452	20.0	2171	2131	846	39.7	2027	-5.4	0.58
Water, g	2408	659	27.4	2347	2522	1216	48.2	2388	4.7	0.47
Protein, g	79.9	19.5	24.3	75.9	74.4	40.0	53.8	68.0	-7.0	0.47
Total fat, g	70.9	18.3	25.8	67.7	70.2	40.4	57.5	62.2	-1.0	0.43
SFA, g	20.2	5.6	27.6	19.8	22.0	14.2	64.5	19.7	9.0	0.34
MUFA, g	26.2	7.5	28.4	25.9	25.1	14.2	56.5	22.2	-4.3	0.43
PUFA, g	14.7	4.3	29.3	13.6	14.8	8.7	59.0	12.4	0.7	0.47
n-3 PUFA, g	2.5	1.1	42.9	2.3	2.4	1.3	54.3	2.2	-3.2	0.53
n-6 PUFA, g	12.0	3.4	28.7	11.3	12.3	7.6	61.6	10.3	2.9	0.42
Cholesterol, mg	362	123	33.9	351	328	237	72.3	288	-9.3	0.46
Carbohydrate, g	289	70	24.3	276	251	99	39.6	237	-13.2	0.65
Total dietary fiber, g	15.7	5.8	37.0	15.3	12.4	8.2	66.4	10.9	-20.9	0.69
Water soluble	3.7	1.4	37.9	3.6	3.0	2.1	68.6	2.4	-20.0	0.66
Water insoluble	11.3	4.4	38.7	10.8	8.9	6.0	67.9	7.6	-21.3	0.70
Ash, g	19.5	4.6	23.8	19.6	18.2	9.4	51.3	16.3	-6.3	0.63
Sodium, mg	4330	1118	25.8	4167	3825	1734	45.3	3550	-11.7	0.41
NaCl, g	10.9	2.8	25.8	10.5	9.7	4.4	45.4	9.0	-11.6	0.39
Potassium, mg	2841	954	33.6	2702	2684	1760	65.6	2344	-5.5	0.75
Na/K ratio, mg/mg	1.6	0.5	29.1	1.6	1.5	0.5	30.3	1.5	-5.7	0.51
Calcium, mg	569	197	34.7	553	633	702	111	485	11.2	0.63
Magnesium, mg	298	88	29.4	288	288	172	59.9	266	-3.4	0.75
Phosphorus, mg	1178	292	24.8	1125	1187	751	63.3	1077	0.8	0.58
Iron, mg	8.8	2.7	30.2	8.5	8.2	4.3	52.6	7.4	-7.5	0.63
Zinc, mg	9.2	2.2	24.0	9.2	8.8	4.5	50.9	8.0	-4.9	0.44
Copper, mg	1.30	0.36	27.5	1.30	1.22	0.67	54.6	1.10	-6.1	0.67
Manganese, mg	3.49	1.27	36.3	3.23	3.15	1.60	50.8	2.66	-9.9	0.60
Retinol, µg	242	222	92.0	190	315	371	118	178	30.5	0.20
α-carotene, µg	406	217	53.6	379	483	555	115	276	18.9	0.46
β-carotene, µg	2985	1793	60.1	2564	2507	2238	89.3	1760	-16.0	0.60
Cryptoxanthin, µg	188	245	130	83	665	1160	175	287	254	0.63

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

†Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

‡Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at $p<0.05$ and $p<0.01$ was indicated by r ≥ 0.25 (0.22 before deattenuation) and r ≥ 0.34 (0.31 before deattenuation), respectively.

§The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 2. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in men (cont.)

(n=89)	12d-WFR				FFQ3					
	Mean	SD	CV	Med	Mean	SD	CV	Med	%[†]	CC[‡]
β-carotene eq, μg	3550	2147	60.5	2991	3089	2690	87.1	2115	-13.0	0.56
Retinol eq, μg	559	312	55.8	469	576	462	80.3	455	3.0	0.47
Lycopene, mcg	2654	2784	105	1887	1561	3217	206	546	-41.2	0.39
Vitamin D, μg	8.0	5.4	67.3	6.8	7.7	5.6	73.1	5.7	-4.2	0.38
α-tocopherol, mg	8.1	2.8	34.0	7.5	7.4	5.3	70.7	6.0	-8.0	0.77
β-tocopherol, mg	0.4	0.1	26.8	0.4	0.4	0.2	64.4	0.3	-9.2	0.38
γ-tocopherol, mg	12.0	3.8	31.9	11.6	13.2	8.1	61.4	11.0	9.8	0.40
δ-tocopherol, mg	3.1	1.1	34.4	3.1	3.3	2.3	71.2	2.8	6.1	0.46
Vitamin K, μg	282	146	51.8	254	287	308	107	211	1.8	0.68
Vitamin B-1, mg	1.12	0.30	27.2	1.10	0.98	0.51	52.2	0.87	-13.0	0.53
Vitamin B-2, mg	1.45	0.42	29.3	1.41	1.47	1.24	84.4	1.27	1.7	0.52
Niacin, mg	20.5	6.2	30.4	19.8	19.6	8.6	44.1	18.6	-4.6	0.43
Vitamin B-6, mg	1.42	0.50	35.2	1.33	1.42	0.74	52.0	1.32	0.1	0.74
Vitamin B12, μg	7.5	4.3	58.0	6.0	6.6	4.3	65.1	5.4	-11.9	0.46
Folate, μg	365	155	42.5	335	322	203	63.1	271	-11.8	0.70
Pantothenic acid, mg	6.85	1.78	26.0	6.72	7.38	5.24	71.1	6.63	7.7	0.57
Vitamin C, mg	109	58	53.7	95	95	82	86.0	66	-12.5	0.73
Daidzein, mg	12.9	7.47	58.1	11.1	19.0	22.0	116	13.7	47.6	0.48
Genistein, mg	21.6	12.8	59.1	19.8	31.3	36.4	116	23.0	44.8	0.48
Median[§]			33.6				64.4			0.52

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

[†]Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

[‡]Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at $p<0.05$ and $p<0.01$ was indicated by $r \geq 0.25$ (0.22 before deattenuation) and $r \geq 0.34$ (0.31 before deattenuation), respectively.

[§]The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 2. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in men (cont.)

(n=89)	FFQ1&3						FFQ1&2&3					
	Mean	SD	CV	Med	%†	CC‡	Mean	SD	CV	Med	%†	CC‡
Energy, kcal	2158	688	31.9	2034	-4.2	0.59	2152	673	31.3	2027	-4.5	0.57
Water, g	2530	1009	39.9	2363	5.1	0.47	2477	914	36.9	2290	2.9	0.50
Protein, g	75.3	29.7	39.4	71.3	-5.8	0.47	74.7	28.7	38.5	72.7	-6.6	0.46
Total fat, g	72.0	35.2	49.0	65.3	1.5	0.55	71.5	34.0	47.5	65.7	0.9	0.57
SFA, g	22.4	12.8	56.9	20.0	11.1	0.46	22.4	12.7	56.6	19.6	10.9	0.50
MUFA, g	26.0	13.1	50.3	24.5	-1.0	0.57	25.8	12.3	47.7	24.1	-1.7	0.59
PUFA, g	15.0	6.6	43.7	13.5	2.1	0.58	14.9	6.3	42.3	13.6	1.2	0.53
n-3 PUFA, g	2.5	1.2	47.2	2.3	0.4	0.63	2.5	1.1	44.7	2.2	-1.7	0.56
n-6 PUFA, g	12.4	5.6	44.7	11.2	3.8	0.53	12.3	5.3	43.3	11.5	3.0	0.49
Cholesterol, mg	334	198	59.2	288	-7.6	0.47	336	185	55.2	306	-7.1	0.54
Carbohydrate, g	256	81	31.5	247	-11.2	0.65	255	81	31.9	242	-11.6	0.67
Total dietary fiber, g	12.5	6.3	50.8	11.6	-20.4	0.76	12.7	6.6	52.0	11.8	-19.2	0.76
Water soluble	3.1	1.6	53.9	2.8	-18.3	0.76	3.1	1.8	56.2	2.9	-16.7	0.78
Water insoluble	8.9	4.5	50.9	8.2	-21.1	0.77	9.0	4.7	52.3	8.2	-20.1	0.76
Ash, g	18.5	7.1	38.6	17.4	-5.2	0.64	18.3	7.1	38.8	17.3	-5.8	0.65
Sodium, mg	3948	1481	37.5	3617	-8.8	0.49	3922	1430	36.5	3716	-9.4	0.50
NaCl, g	10.0	3.7	37.4	9.2	-8.8	0.47	9.9	3.6	36.4	9.4	-9.3	0.48
Potassium, mg	2666	1233	46.2	2462	-6.2	0.80	2650	1265	47.7	2472	-6.7	0.82
Na/K ratio, mg/mg	1.6	0.4	25.7	1.5	-4.6	0.68	1.6	0.4	25.0	1.6	-4.2	0.70
Calcium, mg	599	438	73.1	473	5.2	0.69	598	448	74.8	489	5.1	0.72
Magnesium, mg	286	117	40.9	268	-4.3	0.75	285	121	42.3	265	-4.3	0.74
Phosphorus, mg	1180	516	43.7	1147	0.2	0.57	1174	508	43.2	1106	-0.3	0.59
Iron, mg	8.3	3.4	40.4	7.8	-5.9	0.65	8.3	3.3	39.9	7.8	-5.9	0.63
Zinc, mg	9.0	3.4	37.8	8.4	-2.7	0.42	8.9	3.3	36.7	8.6	-3.1	0.50
Copper, mg	1.23	0.47	38.3	1.18	-5.6	0.70	1.23	0.49	39.4	1.18	-5.2	0.68
Manganese, mg	3.25	1.61	49.6	2.98	-7.0	0.66	3.17	1.44	45.3	2.79	-9.0	0.68
Retinol, µg	310	278	89.6	218	28.5	0.25	305	239	78.2	223	26.4	0.20
α-carotene, µg	471	390	83.0	367	16.0	0.47	460	361	78.4	353	13.3	0.53
β-carotene, µg	2478	1780	71.8	1908	-17.0	0.66	2463	1744	70.8	1869	-17.5	0.71
Cryptoxanthin, µg	640	854	133.5	314	240	0.60	588	705	120	325	213	0.62

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

†Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

‡Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at $p<0.05$ and $p<0.01$ was indicated by r ≥ 0.25 (0.22 before deattenuation) and r ≥ 0.34 (0.31 before deattenuation), respectively.

§The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 2. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in men (cont.)

(n=89)	FFQ1&3						FFQ1&2&3					
	Mean	SD	CV	Med	%†	CC‡	Mean	SD	CV	Med	%†	CC‡
β-carotene eq, µg	3042	2123	69.8	2271	-14.3	0.64	2997	2052	68.5	2337	-15.6	0.68
Retinol eq, µg	567	369	65.1	521	1.5	0.40	559	340	60.8	504	-0.1	0.44
Lycopene, mcg	1786	2833	159	656	-32.7	0.39	1677	2548	152	669	-36.8	0.39
Vitamin D, µg	7.9	5.2	65.4	6.1	-1.3	0.41	7.7	4.6	59.4	6.8	-4.3	0.45
α-tocopherol, mg	7.3	3.9	52.8	6.1	-9.5	0.85	7.2	3.7	51.5	6.1	-10.4	0.86
β-tocopherol, mg	0.4	0.2	45.6	0.3	-8.5	0.50	0.4	0.2	45.0	0.3	-8.7	0.50
γ-tocopherol, mg	13.3	6.1	45.8	11.8	10.5	0.49	13.2	6.0	45.5	11.5	10.4	0.47
δ-tocopherol, mg	3.3	1.6	50.0	3.1	7.1	0.57	3.3	1.7	51.6	3.1	7.2	0.57
Vitamin K, µg	290	204	70.4	262	2.9	0.74	298	241	81.1	256	5.6	0.76
Vitamin B-1, mg	1.00	0.43	43.1	0.96	-11.4	0.47	0.98	0.41	41.4	0.94	-12.5	0.49
Vitamin B-2, mg	1.46	0.82	56.2	1.32	0.8	0.54	1.46	0.84	57.6	1.29	0.5	0.58
Niacin, mg	19.9	7.2	36.4	18.5	-3.2	0.46	19.6	6.7	34.1	18.7	-4.7	0.47
Vitamin B-6, mg	1.43	0.57	40.0	1.34	0.9	0.74	1.42	0.56	39.3	1.36	-0.1	0.77
Vitamin B12, µg	6.8	3.8	56.2	6.3	-8.7	0.47	6.6	3.4	51.0	6.4	-11.1	0.50
Folate, µg	322	169	52.5	286	-11.7	0.70	322	166	51.6	296	-11.9	0.71
Pantothenic acid, mg	7.35	3.39	46.2	6.91	7.4	0.57	7.34	3.51	47.8	6.86	7.2	0.62
Vitamin C, mg	95	71	74.4	78	-12.2	0.77	93	66	70.9	75	-14.5	0.79
Daidzein, mg	18.4	15.2	82.4	15.8	43.4	0.61	18.6	16.2	87.3	14.4	44.4	0.64
Genistein, mg	30.3	25.1	83.1	26.0	40.2	0.61	30.5	26.9	88.2	24.3	41.3	0.64
Median§			49.6			0.58			47.7			0.59

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

†Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

‡Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at $p<0.05$ and $p<0.01$ was indicated by r ≥ 0.25 (0.22 before deattenuation) and r ≥ 0.34 (0.31 before deattenuation), respectively.

§The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 3. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in women

(n=124)	12d-WFR				FFQ3					
	Mean	SD	CV	Med	Mean	SD	CV	Med	%†	CC‡
Energy, kcal	1842	319	17.3	1817	1791	679	37.9	1641	-2.8	0.40
Water, g	2169	625	28.8	2045	2302	935	40.6	2210	6.1	0.50
Protein, g	69.6	15.0	21.6	69.3	68.1	29.6	43.4	60.7	-2.1	0.56
Total fat, g	63.9	13.6	21.2	62.0	67.8	36.7	54.1	60.5	6.2	0.48
SFA, g	18.7	4.1	21.7	18.5	21.7	14.1	65.2	18.4	15.8	0.55
MUFA, g	22.9	5.5	24.1	22.2	23.7	13.0	54.9	21.1	3.6	0.54
PUFA, g	13.0	3.4	26.0	12.9	14.3	6.8	47.5	13.0	10.4	0.28
n-3 PUFA, g	2.2	0.8	38.7	2.0	2.3	1.2	50.6	2.0	8.4	0.48
n-6 PUFA, g	10.6	2.7	25.7	10.7	11.9	5.8	48.3	10.7	12.3	0.26
Cholesterol, mg	323	100	30.9	311	338	320	94.5	285	4.8	0.53
Carbohydrate, g	235	45	19.0	234	210	71	33.7	196	-10.6	0.61
Total dietary fiber, g	15.2	5.8	37.8	14.4	12.9	6.3	48.4	11.8	-15.1	0.43
Water soluble	3.6	1.2	34.5	3.4	3.2	1.6	49.4	2.9	-11.8	0.46
Water insoluble	11.0	4.5	40.8	10.0	9.2	4.5	49.3	8.1	-16.8	0.41
Ash, g	17.6	4.4	24.9	17.5	17.3	7.6	44.0	15.3	-1.8	0.52
Sodium, mg	3780	1014	26.8	3642	3579	1722	48.1	3254	-5.3	0.62
NaCl, g	9.6	2.6	26.8	9.2	9.0	4.4	48.7	8.1	-5.4	0.62
Potassium, mg	2697	879	32.6	2538	2621	1151	43.9	2323	-2.8	0.57
Na/K ratio, mg/mg	1.5	0.4	27.1	1.5	1.4	0.4	27.6	1.4	-6.1	0.51
Calcium, mg	559	185	33.0	530	619	445	71.9	532	10.7	0.47
Magnesium, mg	273	79	29.1	262	268	106	39.6	243	-2.0	0.58
Phosphorus, mg	1064	248	23.3	1049	1106	534	48.3	975	3.9	0.59
Iron, mg	8.5	2.7	31.7	8.2	8.2	3.3	40.3	7.8	-2.8	0.48
Zinc, mg	8.0	1.7	21.5	7.8	7.9	3.3	41.5	7.0	-1.2	0.48
Copper, mg	1.17	0.31	26.8	1.15	1.16	0.41	35.4	1.13	-1.1	0.47
Manganese, mg	3.81	3.13	82.2	2.98	3.09	1.54	49.7	2.69	-18.8	0.64
Retinol, µg	233	223	95.8	179	323	347	108	187	38.4	0.45
α-carotene, µg	412	241	58.5	381	522	582	112	350	26.5	0.46
β-carotene, µg	2929	1759	60.1	2542	2910	2717	93.4	2294	-0.6	0.47
Cryptoxanthin, µg	225	257	114	140	685	936	137	343	204	0.31

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

†Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

‡Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at $p<0.05$ and $p<0.01$ was indicated by $r \geq 0.22$ (0.19 before deattenuation) and $r \geq 0.26$ (0.23 before deattenuation), respectively.

§The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 3. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in women (cont.)

(n=124)	12d-WFR				FFQ3					
	Mean	SD	CV	Med	Mean	SD	CV	Med	%†	CC‡
β-carotene eq, μg	3524	2030	57.6	3089	3528	3078	87.2	2973	0.1	0.41
Retinol eq, μg	541	283	52.3	462	621	458	73.9	489	14.8	0.34
Lycopene, mcg	3042	3857	127	2006	2621	4252	162	822	-13.8	0.51
Vitamin D, μg	6.7	4.6	68.9	5.6	7.1	5.5	77.8	5.5	6.3	0.47
α-tocopherol, mg	8.0	3.9	48.3	7.3	7.8	4.4	56.9	7.0	-2.5	0.48
β-tocopherol, mg	0.4	0.3	66.1	0.4	0.4	0.2	50.3	0.3	-8.2	0.37
γ-tocopherol, mg	11.1	3.4	31.1	10.5	13.7	7.3	53.1	12.7	23.7	0.18
δ-tocopherol, mg	2.8	1.0	35.4	2.6	3.2	1.5	46.5	3.2	16.4	0.42
Vitamin K, μg	269	141	52.5	240	293	184	62.8	267	9.1	0.55
Vitamin B-1, mg	0.99	0.23	23.3	0.96	0.91	0.39	43.5	0.81	-7.9	0.48
Vitamin B-2, mg	1.35	0.36	26.7	1.30	1.45	0.85	58.6	1.27	7.2	0.53
Niacin, mg	17.9	5.6	31.0	17.4	17.0	7.4	43.4	15.9	-5.3	0.49
Vitamin B-6, mg	1.27	0.42	32.9	1.20	1.28	0.54	42.3	1.15	1.1	0.55
Vitamin B12, μg	6.4	3.8	59.5	5.4	6.0	3.9	65.0	5.0	-6.8	0.45
Folate, μg	369	151	40.9	337	349	172	49.4	333	-5.4	0.45
Pantothenic acid, mg	6.12	1.52	24.8	6.05	6.80	3.18	46.9	6.16	11.1	0.51
Vitamin C, mg	111	57	51.6	100	107	70	65.5	91	-4.0	0.51
Daidzein, mg	12.6	7.2	57.4	11.5	19.2	13.2	68.7	17.4	52.5	0.53
Genistein, mg	21.2	12.4	58.5	19.3	32.2	23.4	72.8	27.6	52.0	0.51
Median§			32.6				49.4			0.48

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

†Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

‡Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at $p<0.05$ and $p<0.01$ was indicated by $r \geq 0.22$ (0.19 before deattenuation) and $r \geq 0.26$ (0.23 before deattenuation), respectively.

§The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 3. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in women (cont.)

(n=124)	FFQ1&3						FFQ1&2&3					
	Mean	SD	CV	Med	%†	CC‡	Mean	SD	CV	Med	%†	CC‡
Energy, kcal	1875	670	35.7	1768	1.8	0.44	1890	616	32.6	1813	2.6	0.48
Water, g	2362	922	39.0	2356	8.9	0.58	2360	905	38.3	2346	8.8	0.63
Protein, g	71.3	33.4	46.8	65.7	2.5	0.60	72.1	28.5	39.5	68.1	3.7	0.64
Total fat, g	71.3	37.4	52.4	64.4	11.7	0.54	72.1	33.6	46.6	65.3	12.9	0.52
SFA, g	22.9	14.1	61.6	20.4	22.0	0.58	23.1	12.4	53.8	21.0	23.1	0.61
MUFA, g	25.0	12.9	51.6	23.2	9.3	0.59	25.4	12.0	47.2	23.5	10.8	0.57
PUFA, g	15.0	7.1	47.1	13.5	15.4	0.39	15.1	6.5	43.4	14.2	16.3	0.35
n-3 PUFA, g	2.5	1.3	53.1	2.2	14.3	0.49	2.5	1.1	46.4	2.3	14.6	0.51
n-6 PUFA, g	12.5	5.8	46.9	11.3	17.1	0.38	12.6	5.5	44.1	11.4	18.2	0.34
Cholesterol, mg	332	237	71.5	283	2.7	0.56	344	213	61.9	297	6.5	0.57
Carbohydrate, g	218	65	29.7	214	-7.0	0.65	220	61	27.5	214	-6.3	0.66
Total dietary fiber, g	13.6	6.5	47.8	12.4	-11.0	0.51	13.6	6.0	44.4	12.1	-10.9	0.50
Water soluble	3.4	1.7	49.6	3.0	-6.9	0.58	3.3	1.5	45.0	3.0	-7.7	0.56
Water insoluble	9.6	4.5	47.3	8.9	-12.8	0.50	9.7	4.3	44.7	8.7	-12.4	0.48
Ash, g	18.1	7.7	42.6	16.3	2.5	0.62	18.2	6.9	38.1	17.0	3.3	0.67
Sodium, mg	3735	1608	43.1	3476	-1.2	0.64	3769	1496	39.7	3527	-0.3	0.68
NaCl, g	9.4	4.1	43.4	8.7	-1.2	0.63	9.5	3.8	39.9	8.9	-0.4	0.67
Potassium, mg	2741	1223	44.6	2396	1.6	0.59	2749	1107	40.3	2487	1.9	0.64
Na/K ratio, mg/mg	1.4	0.3	24.5	1.4	-5.7	0.51	1.4	0.3	24.1	1.4	-5.0	0.56
Calcium, mg	649	443	68.2	554	16.0	0.54	657	394	60.0	596	17.4	0.58
Magnesium, mg	278	118	42.2	252	2.0	0.65	280	107	38.2	257	2.4	0.67
Phosphorus, mg	1155	595	51.5	1037	8.6	0.62	1168	508	43.5	1108	9.8	0.64
Iron, mg	8.5	3.5	41.8	8.1	0.5	0.52	8.5	3.1	36.9	8.4	0.8	0.52
Zinc, mg	8.3	3.5	41.8	7.8	3.5	0.51	8.4	3.0	35.4	8.1	4.9	0.55
Copper, mg	1.21	0.47	38.7	1.17	3.3	0.58	1.21	0.41	33.9	1.18	3.4	0.56
Manganese, mg	3.14	1.34	42.7	2.91	-17.7	0.72	3.16	1.31	41.6	2.85	-17.1	0.72
Retinol, µg	313	284	90.8	208	34.0	0.32	313	234	74.7	226	34.2	0.37
α-carotene, µg	544	457	84.1	424	31.9	0.37	540	415	76.8	430	31.0	0.48
β-carotene, µg	2999	2013	67.1	2595	2.4	0.39	2979	1964	65.9	2497	1.7	0.47
Cryptoxanthin, µg	730	1048	144	420	225	0.23	685	833	122	439	204	0.22

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

†Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

‡Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at p<0.05 and p<0.01 was indicated by r ≥ 0.22 (0.19 before deattenuation) and r ≥ 0.26 (0.23 before deattenuation), respectively.

§The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 3. Energy and nutrient intakes and coefficient of variance based on single or multiple FFQ and 12d-WFR, percentage differences between intakes by single or multiple FFQ and 12d-WFR and their correlation in women (cont.)

(n=124)	FFQ1&3						FFQ1&2&3					
	Mean	SD	CV	Med	%†	CC‡	Mean	SD	CV	Med	%†	CC‡
β-carotene eq, µg	3652	2398	65.7	3152	3.6	0.33	3608	2300	63.7	3122	2.4	0.43
Retinol eq, µg	621	378	60.9	528	14.8	0.22	618	335	54.2	498	14.2	0.29
Lycopene, mcg	3280	7794	238	1011	7.8	0.52	3082	6058	197	1184	1.3	0.49
Vitamin D, µg	7.5	6.0	79.5	6.3	12.6	0.56	7.6	5.7	74.2	6.7	14.3	0.56
α-tocopherol, mg	7.9	3.7	46.7	7.2	-1.0	0.51	8.0	3.8	47.6	7.3	0.1	0.50
β-tocopherol, mg	0.4	0.2	45.2	0.4	-4.4	0.42	0.4	0.2	43.0	0.4	-3.9	0.42
γ-tocopherol, mg	14.2	6.6	46.5	13.1	27.8	0.27	14.3	6.3	43.9	13.0	28.6	0.26
δ-tocopherol, mg	3.4	1.9	55.6	3.3	23.8	0.49	3.4	1.6	47.7	3.3	23.7	0.50
Vitamin K, µg	312	246	78.9	290	16.1	0.64	310	210	67.8	285	15.2	0.66
Vitamin B-1, mg	0.97	0.43	44.2	0.89	-1.7	0.41	0.97	0.38	38.9	0.91	-1.8	0.50
Vitamin B-2, mg	1.49	0.85	57.0	1.31	10.4	0.51	1.51	0.72	48.1	1.38	11.5	0.57
Niacin, mg	17.8	7.8	43.6	16.2	-0.8	0.57	17.9	7.2	40.3	16.2	-0.1	0.57
Vitamin B-6, mg	1.34	0.56	41.5	1.21	6.0	0.63	1.35	0.51	37.5	1.22	6.4	0.64
Vitamin B12, µg	6.3	4.2	67.3	5.2	-1.4	0.50	6.3	3.7	58.4	5.4	-1.8	0.47
Folate, µg	358	165	46.1	326	-3.0	0.49	360	157	43.7	335	-2.5	0.49
Pantothenic acid, mg	7.11	3.46	48.7	6.51	16.2	0.54	7.16	2.95	41.1	6.61	17.1	0.59
Vitamin C, mg	112	68	60.5	94	0.5	0.58	111	65	58.1	93	0.0	0.57
Daidzein, mg	20.7	18.7	90.3	17.3	64.7	0.61	20.2	15.0	74.3	17.1	60.7	0.63
Genistein, mg	34.6	31.5	90.8	29.2	63.5	0.60	33.8	25.3	74.9	29.1	59.5	0.63
Median§			47.8			0.54			44.4			0.56

12d-WFR, 12-day weighed food records; SD, standard deviation; CV, coefficient of variance; Med, median; CC, correlation coefficient; FFQ1&3, the average of energy and nutrient intakes from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes from FFQ1 and FFQ2 and FFQ3.

†Percentage differences of mean values: (FFQ − 12d-WFR)/12d-WFR × 100 (%).

‡Sperman's rank correlation coefficients between intakes by FFQs and by 12d-WFR were based on energy-adjusted values using the residual methods (other than energy and Na/K ratio) and were expressed as deattenuated CC; Deattenuated CCx=observed CCx×SQRT (1+λx/n), where λx is the ratio of within- to between-individual variance for nutrients x, and n is number of dietary records; Statistical significance at *p*<0.05 and *p*<0.01 was indicated by r ≥ 0.22 (0.19 before deattenuation) and r ≥ 0.26 (0.23 before deattenuation), respectively.

§The median values of the CVs and CCs (vs. 12-day WFR) for energy and 48 energy-adjusted nutrient intakes were calculated.

number. In women, a single FFQ underestimated nutrient intakes, while multiple FFQs showed overestimation. Most SDs of each nutrient intake became smaller when intakes from 2 or 3 FFQs were averaged compared to a single FFQ. The SDs of energy intake based on FFQ3, FFQ1&3, and FFQ1&2&3 were 846, 688, and 673 in men and 679, 670, and 616 in women. The median CVs of energy and nutrient intakes for FFQ3, FFQ1&3, and FFQ1&2&3 became smaller (64.4, 49.6, and 47.7, respectively) as the number of FFQs increased in men, similar to those in women. The median values across the CCs (vs. 12-day WFR) of energy and 48 energy-adjusted nutrient intakes based on FFQ3, FFQ1&3, and FFQ1&2&3 improved as the number of FFQs increased for both sex: corresponding median (range) CCs were 0.52 (0.20–0.77), 0.58 (0.25–0.85), and 0.59 (0.20–0.86), respectively, in men and 0.48 (0.18–0.64), 0.54 (0.22–0.72), and 0.56 (0.22–0.72), respectively, in women (Table 2-1, 2-2). The number of nutrients that improved their CCs for FFQ1&3 or FFQ1&2&3 compared to those for FFQ3 was 39 and 43, respectively, in men, and 41 and 45, respectively, in women. While most nutrients showed correlation coefficients of 0.3–0.4 or higher, the percentage differences were greater than 10% for most vitamins and exceeded 200% for cryptoxanthin in both men and women. Additionally, using FFQ2&3 as the two FFQs provided results similar to those of FFQ1&3. The corresponding median CCs for energy and 48 energy-adjusted nutrient intakes were r = 0.55 for men and 0.53 for women (data not shown).

Cross-classification by quintile and the weighted kappa statistic

Tables 4 and 5 show the agreement between the respective intake rankings by the FFQs and 12-day WFR, with cross-classification by quintile in men and women. The proportion of subjects classified into the opposite extreme category was 5% or less for most nutrients, regardless of the number of FFQs, in both sexes. The median percentage of those classified in the opposite category was 1% in men and 2% in women for a single FFQ, and these results remained consistent even with an increased number of FFQs. Conversely, the percentages of those classified in the same and adjacent quintiles for estimates based on multiple FFQ intakes were improved for many nutrients, for both men and women, compared to estimates based on a single FFQ intake.

The percentages of those classified in the same and adjacent quintiles for the estimates by multiple FFQs intake were improved in most nutrients for either gender compared with those by a single FFQ intake, but the degree of improvement was not remarkable. Moreover, the range of category agreement based on the weighted kappa coefficient was poor to moderate in single and multiple FFQs.

Comparison of the single FFQ and the reproducibility

We also examined the reproducibility of dietary intake estimated by FFQ1 and FFQ3 administered at a two-year interval and by FFQ2 and FFQ3 administered at a one-year interval (Supplementary Table 1 and 2). Energy and nutrient intakes estimated using FFQ1 or FFQ2 were compared to those estimated using FFQ3. Statistical differences were observed in some nutrients for either FFQs and FFQ3; however, based on Bonferroni's correction, considering multiple comparisons, only cholesterol intake in women comparing FFQ2 and FFQ3 showed a statistically significant difference ($p < 0.001$). The median (range) values of ICCs between FFQ1 (2 years before FFQ3) and FFQ3 for energy and energy-adjusted nutrient intakes were 0.51 (0.32–0.76) and 0.55 (0.28–0.71) in men and women, respectively. For ICCs between FFQ2 (one year before FFQ3) and FFQ3, there was a relatively improved agreement of 0.68 (0.47–0.79) in men and 0.64 (0.45–0.74) in women.

DISCUSSION

The validity of ranking adult Japanese individuals by dietary intake was assessed using single and multiple FFQs, with the 12-day WFR data as the reference standard. The deattenuated, energy-adjusted CCs between the intake based on FFQ3 as the single FFQ and 12-day WFR were moderate for many nutrients. These CCs for the multiple FFQs were slightly higher than those of single FFQ. However, the proportion of subjects classified into the opposite extreme category was ≤5% for most nutrients, regardless of the number of FFQs used.

This study evaluated the validity of FFQ-based estimates incorporating the response option "constitutionally unable to eat or drink it".15 Correlations with intakes based on the 12-day WFR were generally moderate to high, ranging from approximately 0.5 to 0.7 for food groups with either a moderate number of responses indicating inedibility (e.g., meat and seafood) or relatively few such responses (e.g., cereals and vegetables). Additionally, the validity of protein intake estimates (primarily from meat and seafood) using this FFQ (r ≈ 0.5–0.6) was comparable to that of FFQs without this response option (r ≈ 0.5–0.7) for the same items.[8] Also, retinol, n-6 PUFA, and gamma-tocopherol intakes showed relatively low correlations (r ≈ 0.2–0.4), whereas carbohydrates and manganese had high correlations (r ≥ 0.6). These findings were consistent with those from a validation study of the same FFQ conducted similarly but without the response option "constitutionally unable to eat or drink it".[14] Further, many nutrients, including vitamins, showed intake differences significantly greater than 10%. However, in cohort studies, FFQs are generally used to rank individuals based on relative intake amounts. For this purpose, the validity of nutrient intakes estimated by the FFQ can be considered moderate or higher in accuracy.

The validities for most nutrient intake estimates based on a single FFQ were moderately similar to previous studies on Japanese adults[21] or based on FFQs from the same JPHC-FFQ.[7, 8, 14] In a validation study for the original 138 food and beverage items in JPHC-FFQ, Ishihara et al.[7] reported that for the estimation of most nutrients by FFQ, the CC range was 0.3–0.6, comparing to the 28-day WFR among adults. Takachi et al.[8] also reported the validity of the 138-item FFQ, with the same food list as in this study after revision; compared to the four-day WFR among urban cancer examinees, the median CCs (range) were 0.57 (0.23–0.89) for men and 0.47 (0.08–0.94) for women. In another recent validation study of 172-item FFQ in a subsample of cohort study in Japan, compared

Table 4. Cross-classification by quintile (%) and weighted kappa values of energy-adjusted nutrient intakes by single or multiple FFQ and 12d-WFR in men (n=89)

	FFQ3 vs. 12d-WFR				FFQ1&3 vs. 12d-WFR				FFQ1&2&3 vs. 12d-WFR			
	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ
Energy[†]	34	78	0	0.38	37	74	0	0.39	34	74	0	0.36
Water	31	76	3	0.35	35	75	4	0.35	35	75	4	0.35
Protein	29	74	3	0.31	37	69	4	0.32	35	71	3	0.32
Total fat	30	64	2	0.25	36	71	2	0.36	35	78	3	0.38
SFA	27	69	3	0.22	33	70	5	0.31	30	72	3	0.31
MUFA	25	67	3	0.25	37	73	3	0.36	35	74	3	0.36
PUFA	26	71	0	0.28	36	72	0	0.36	30	69	0	0.31
n-3 PUFA	31	69	1	0.29	35	74	1	0.38	35	70	1	0.34
n-6 PUFA	24	67	1	0.21	33	66	0	0.32	22	66	1	0.25
Cholesterol	26	69	2	0.25	33	66	2	0.28	34	78	3	0.35
Carbohydrate	36	79	0	0.42	37	80	0	0.43	37	80	1	0.42
Total dietary fiber	35	79	0	0.45	51	87	0	0.59	49	87	0	0.58
Water soluble	34	76	0	0.41	45	85	0	0.52	54	85	0	0.59
Water insoluble	42	81	0	0.51	45	83	0	0.53	49	83	0	0.56
Ash	34	82	0	0.43	35	79	0	0.42	36	75	0	0.41
Sodium	27	62	1	0.22	26	66	2	0.25	26	66	2	0.27
NaCl	28	61	0	0.22	27	69	2	0.27	28	69	2	0.28
Potassium	45	80	0	0.52	42	85	0	0.53	40	90	0	0.55
Na/K ratio[a]	39	71	1	0.35	35	78	0	0.41	42	75	0	0.45
Calcium	31	80	1	0.38	37	84	0	0.46	40	84	0	0.49
Magnesium	39	88	1	0.51	43	89	0	0.53	43	88	0	0.53
Phosphorus	36	71	2	0.35	34	78	2	0.36	33	78	1	0.36
Iron	47	75	1	0.46	40	79	1	0.45	45	75	1	0.46
Zinc	29	69	4	0.27	33	65	3	0.27	36	67	3	0.31
Copper	36	78	1	0.43	36	79	0	0.43	37	79	0	0.43
Manganese	38	74	1	0.41	39	78	0	0.45	38	82	0	0.46
Retinol	22	63	6	0.14	26	64	6	0.18	24	64	7	0.14
α-carotene	28	66	2	0.24	26	66	1	0.24	21	63	1	0.21
β-carotene	37	72	2	0.38	38	74	0	0.43	43	75	0	0.46
Cryptoxanthin	27	74	0	0.34	30	73	0	0.34	30	74	0	0.35

12d-WFR, 12-day weighed food records; κ, weighted kappa values; FFQ1&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ2 and FFQ3.
[†]Cross-classification for energy intake and Na/K ratio were calculated by using crude values.
[§]The median values of percentages and κ for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 4. Cross-classification by quintile (%) and weighted kappa values of energy-adjusted nutrient intakes by single or multiple FFQ and 12d-WFR in men (n=89) (cont.)

	FFQ3 vs. 12d-WFR				FFQ1&3 vs. 12d-WFR				FFQ1&2&3 vs. 12d-WFR			
	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ
β-carotene eq	33	71	3	0.34	38	79	0	0.43	39	78	0	0.43
Retinol eq	24	74	5	0.28	26	73	7	0.27	26	78	7	0.29
Lycopene	34	60	5	0.24	33	67	5	0.28	31	67	5	0.27
Vitamin D	27	63	5	0.21	27	70	6	0.24	33	69	5	0.27
α-tocopherol	46	85	0	0.55	46	90	0	0.59	46	94	0	0.62
β-tocopherol	29	60	3	0.18	30	67	2	0.27	34	66	2	0.29
γ-tocopherol	29	63	3	0.24	22	64	1	0.24	22	65	1	0.22
δ-tocopherol	30	69	2	0.28	36	71	0	0.36	30	72	0	0.34
Vitamin K	37	85	1	0.48	44	82	0	0.52	49	84	0	0.56
Vitamin B-1	29	72	2	0.32	27	71	3	0.28	25	71	3	0.27
Vitamin B-2	37	70	1	0.35	33	71	2	0.34	34	73	1	0.36
Niacin	34	74	3	0.31	38	69	2	0.31	38	75	3	0.34
Vitamin B-6	43	84	0	0.52	44	81	0	0.51	42	85	0	0.52
Vitamin B12	24	64	1	0.24	28	69	5	0.25	33	72	3	0.29
Folate	35	82	0	0.45	40	83	1	0.48	44	83	1	0.51
Pantothenic acid	39	75	2	0.39	37	72	3	0.36	35	81	2	0.41
Vitamin C	39	82	0	0.49	37	78	0	0.46	37	84	0	0.51
Daidzein	31	67	2	0.28	39	76	1	0.41	38	76	1	0.41
Genistein	30	67	2	0.28	36	75	1	0.38	39	76	1	0.42
Median[§]	31	72	1	0.34	36	74	1	0.36	35	75	1	0.36

12d-WFR, 12-day weighed food records; κ, weighted kappa values; FFQ1&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ2 and FFQ3.
[†]Cross-classification for energy intake and Na/K ratio were calculated by using crude values.
[§]The median values of percentages and κ for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 5. Cross-classification by quintile (%) and weighted kappa values of energy-adjusted nutrient intakes by single or multiple FFQ and 12d-WFR in women (n=124)

	FFQ3 vs. 12d-WFR				FFQ1&3 vs. 12d-WFR				FFQ1&2&3 vs. 12d-WFR			
	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ
Energy[†]	31	73	5	0.28	31	71	4	0.30	34	71	4	0.31
Water	30	69	3	0.28	32	77	2	0.37	36	81	2	0.43
Protein	29	73	1	0.34	33	73	1	0.36	36	75	1	0.40
Total fat	35	72	2	0.34	26	69	2	0.28	27	70	2	0.30
SFA	31	71	2	0.32	31	74	1	0.33	30	74	2	0.33
MUFA	36	73	2	0.35	36	76	2	0.38	37	75	3	0.37
PUFA	19	61	5	0.13	28	64	3	0.23	27	61	2	0.20
n-3 PUFA	30	69	3	0.27	24	68	3	0.25	23	69	4	0.24
n-6 PUFA	22	60	7	0.12	28	64	3	0.22	25	61	4	0.16
Cholesterol	31	67	2	0.29	27	68	1	0.28	32	69	0	0.33
Carbohydrate	39	81	2	0.44	37	73	1	0.40	33	77	1	0.40
Total dietary fiber	30	69	3	0.27	31	73	3	0.32	32	76	4	0.33
Water soluble	35	67	2	0.30	31	73	1	0.34	35	71	0	0.36
Water insoluble	28	69	4	0.25	31	74	4	0.33	28	74	6	0.30
Ash	34	71	2	0.32	36	76	0	0.40	37	79	1	0.45
Sodium	38	78	0	0.41	37	77	0	0.40	43	79	0	0.45
NaCl	39	75	0	0.40	39	77	0	0.40	43	79	0	0.45
Potassium	34	76	2	0.36	35	74	2	0.36	45	77	2	0.45
Na/K ratio[a]	33	72	1	0.33	36	71	0	0.36	33	69	0	0.35
Calcium	29	66	2	0.26	29	74	2	0.32	30	71	1	0.32
Magnesium	35	70	0	0.36	34	72	0	0.37	31	78	0	0.40
Phosphorus	27	71	1	0.31	31	74	2	0.35	37	77	2	0.42
Iron	32	72	4	0.31	33	71	1	0.33	32	69	1	0.32
Zinc	33	68	2	0.31	32	69	2	0.30	32	73	3	0.33
Copper	30	68	2	0.27	34	73	2	0.36	34	73	2	0.35
Manganese	39	77	0	0.42	39	82	0	0.48	44	81	0	0.50
Retinol	27	68	3	0.26	23	64	5	0.17	27	69	6	0.23
α-carotene	30	67	2	0.27	23	63	2	0.18	27	65	0	0.23
β-carotene	34	69	4	0.30	29	68	6	0.25	32	72	6	0.30
Cryptoxanthin	23	62	4	0.13	25	61	7	0.12	19	61	7	0.09

12d-WFR, 12-day weighed food records; κ, weighted kappa values; FFQ1&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ2 and FFQ3.

[†]Cross-classification for energy intake and Na/K ratio were calculated by using crude values.

[§]The median values of percentages and κ for energy and 48 energy-adjusted nutrient intakes were calculated.

Table 5. Cross-classification by quintile (%) and weighted kappa values of energy-adjusted nutrient intakes by single or multiple FFQ and 12d-WFR in women (n=124) (cont.)

	FFQ3 vs. 12d-WFR				FFQ1&3 vs. 12d-WFR				FFQ1&2&3 vs. 12d-WFR			
	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ	Same category	Same and adjacent category	Extreme category	κ
β-carotene eq	36	69	5	0.31	29	65	4	0.22	33	69	4	0.28
Retinol eq	34	61	3	0.22	26	55	5	0.11	29	57	6	0.15
Lycopene	38	69	2	0.33	33	71	2	0.31	27	70	2	0.26
Vitamin D	39	72	3	0.33	43	76	3	0.41	36	77	3	0.38
α-tocopherol	30	70	2	0.30	32	66	2	0.31	31	67	2	0.30
β-tocopherol	19	60	2	0.14	23	61	2	0.17	23	62	2	0.18
γ-tocopherol	24	57	7	0.10	23	57	3	0.13	26	57	3	0.16
δ-tocopherol	23	61	2	0.19	22	65	0	0.22	25	66	0	0.24
Vitamin K	31	73	2	0.34	36	71	0	0.39	35	74	0	0.40
Vitamin B-1	29	67	2	0.26	29	61	2	0.21	34	67	2	0.29
Vitamin B-2	29	68	0	0.30	30	71	2	0.31	27	73	0	0.31
Niacin	31	66	2	0.29	35	73	2	0.37	37	71	1	0.37
Vitamin B-6	35	77	2	0.38	42	78	2	0.44	40	76	2	0.42
Vitamin B12	34	65	3	0.26	38	66	4	0.29	37	65	4	0.28
Folate	40	71	4	0.34	36	73	3	0.35	35	73	3	0.34
Pantothenic acid	29	73	0	0.32	37	77	2	0.39	42	76	0	0.43
Vitamin C	39	74	2	0.36	38	77	2	0.40	34	78	2	0.38
Daidzein	29	71	3	0.29	31	69	2	0.33	37	70	1	0.37
Genistein	24	69	2	0.25	31	73	2	0.35	33	71	1	0.36
Median[§]	31	69	2	0.30	31	71	2	0.33	33	71	2	0.33

12d-WFR, 12-day weighed food records; κ, weighted kappa values; FFQ1&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ3; FFQ1&2&3, the average of energy and nutrient intakes were calculated from FFQ1 and FFQ2 and FFQ3.

[†]Cross-classification for energy intake and Na/K ratio were calculated by using crude values.

[§]The median values of percentages and κ for energy and 48 energy-adjusted nutrient intakes were calculated.

to the 12-day WFR by Yokoyama et al.,[14] the median CCs (range) were 0.50 (0.01–0.82) for men and 0.43 (0.14–0.47) for women, similar to the present study.

Previous cohort study among American women showed that the measurement of multiple exposures allowed the analysis considering habitual dietary changes in the association between dietary fat and coronary heart disease.[22] In the present validation study, the CC values for most nutrients improved with each repeated FFQ administration. The SD and CV of estimated nutrient intakes became smaller with the averaging of FFQs. This suggests that the effects of intra-individual variability may decrease, allowing multiple FFQs to reflect more habitual intake. We speculate that this is one reason for the improved CCs observed in this study. A validity study of FFQs (used in the cohort study described above) in American women assessed the improvement in the ability to estimate long-term dietary measures using the average intake of two FFQs conducted in 1980 and 1986 or the average intake of three FFQs, with the addition of the one conducted in 1984. These CCs between FFQs and diet records improved to 0.57 (for one FFQ), 0.79 (for two FFQs), and 0.83 (for three FFQs) for the total fat.10 Similarly, for protein, corresponding values were reported to be 0.50, 0.65, and 0.68, indicating stronger correlations. However, it's worth noting that the degree of improvement in the CCs in this study was not consistent with the previous study. The disparity may be attributed to our study not updating the WFR through long-term follow-up as the reference standard. In contrast, previous studies calculated CCs using the cumulative average intake of the reference standard over extended periods, alongside multiple FFQs.

Kobayashi et al. also conducted a validity study on self-administered diet history questionnaires (asking the preceding month's diet) in middle aged Japanese people; then, in that study, questionnaires were used to survey the diet four times for one year.[11] The reported median CC compared to the 16-day semi-weighing diet records was higher for the average of four questionnaire-obtained intakes than for only one questionnaire. Although there are differences in recall periods and implementation intervals, as in our study, the correlation was stronger when using the average intake of multiple dietary questionnaires.

Conversely, this is the first report to evaluate the effect of the repeated conduction on the degree of ranking agreement by intake from the FFQs used in a large cohort study in Japan. Results showed that the percentage of most nutrients classified in the opposite category was ≤5%, and this percentage did not improve markedly even with the average of multiple FFQs. The kappa coefficient, which indicates the degree of agreement in classification, also did not improve significantly with multiple FFQs. Therefore, even the usage of estimates from a single FFQ is not necessarily likely to result in a serious misclassification than using intake from the multiple FFQs.

This study has several limitations. First, it's worth noting that social transformations, such as lifestyle changes due to external factors like the COVID-19 pandemic, occurred during the study period. These significant lifestyle changes affected the study's design. Since the 12-day WFR for all four seasons took two years to complete, none of the FFQs perfectly matched the recall term and execution period of the 12-day WFR. However, the differences between most nutrient intakes of FFQ3 and FFQ1 or FFQ2 were not substantial, and the CCs between FFQ1, FFQ2, or FFQ3 and the 12-day WFR did not differ significantly. Therefore, the effect on the CCs due to the differences in the periods of data collection appears to be minimal. Second, as the period of the dietary record survey in this study was limited to two years, it could not be ruled out the possibility that the degree of agreement in the rankings would have improved if it had been based on a long-term survey covering multiple FFQs (although the number of people in the extreme categories was less than 5% for most nutrients even in the single FFQ). The validation study in the Nurses' Health Study demonstrated that comparing multiple FFQs with habitual estimates over a 6-year period (1980–1986) improved validity.[10] In contrast, our study used a shorter reference period of 2 years, which may explain the limited improvement in validity despite multiple FFQs. Third, subjects were not selected through random sampling. Maintaining a food diary for two years requires considerable motivation, which may have resulted in a sample biased toward more health-conscious individuals. Therefore, the possibility of overestimating our results cannot be ruled out. Finally, the FFQ relied on subjects' memories to report the frequency of food intake over the past years. Since the same questionnaires were administered thrice at one-year intervals, there might have been unintentional similarities in responses between surveys. However, even if there was overestimation, it had a limited impact, as the CCs for FFQ1 were essentially the same as those for FFQ3, with corresponding median CC values of 0.54 and 0.52 for men and 0.47 and 0.48 for women (Supplementary Table 1).

In conclusion, the single FFQ used in TMM cohort studies showed a moderate validity in adult residents of the cohort area. The percentage of participants classified in the opposite quintile category was less than 5% for most nutrients. Furthermore, conducting the FFQ multiple times slightly improved the accuracy of intake estimates. Nevertheless, the use of estimates from a single FFQ is unlikely to result in a serious misclassification compared to using intake from multiple FFQs over a relatively short period.

SUPPLEMENTARY MATERIALS

All supplementary tables and figures are available upon request.

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

The industry (in part, from KAGOME CO. LTD. JAPAN) members were involved in the study as author (hypothesis/design, execution, analysis, or interpretation), and their fund was mainly used for personnel expenses in local dietitian for the collection and check of food record used as reference method in this study. All the research materials (FFQ, reference method and its standardization) were independent from the industry and academic independence was not affected in this validation study.)

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