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Reproducibility and validity of a food frequency questionnaire for nutrient intakes in the study areas of large-scale cohort studies in Japan

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ABSTRACT

The Japan Multi-Institutional Collaborative Cohort Study, the Yamagata Molecular Epidemiological Cohort Study, and the Tsuruoka Metabolomics Cohort Study use a 47-item food frequency questionnaire (FFQ) developed in central Japan in 2004. We applied regression analyses to estimate nutrient intakes in the FFQ. The regression equations, however, may not be so robust and may vary among areas, even in Japan. We aimed to evaluate the reproducibility and validity of the FFQ over an expanded area of Japan. Healthy volunteers aged 34–70 years from 13 areas of Japan provided 12-day weighed dietary records (WDRs) and completed two FFQs over 1 year. We evaluated reproducibility and validity by comparing the intakes of 27 nutrients between the two FFQs and the first FFQ (FFQ1) and WDRs, respectively. Spearman's rank correlation coefficients (SRs) between estimates from the FFQs and WDRs were calculated

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and corrected for intra-individual variation in the WDRs. Intakes of the selected nutrients estimated from the two FFQs were equivalent. The median energy-adjusted SRs between FFQ1 and the second FFQ were 0.66 for both men and women. Regarding validity adjusted for within-individual variation, energy-adjusted SRs for WDRs vs FFQ1 ranged from 0.13 (thiamin) to 0.79 (alcohol) for men, and the median was 0.35. The energy-adjusted SRs ranged from 0.20 (protein) to 0.71 (alcohol) for women, and the median was 0.43. The FFQ demonstrated high reproducibility and moderate validity, which suggests that it is appropriate to clarify associations between diet and health and/or disease among adults in Japan.

Keywords: food frequency questionnaire, weighed dietary record, validity, reproducibility, correlation coefficient

Abbreviations:
FFQ: food frequency questionnaire
J-MICC: Japan Multi-institutional Collaborative Cohort
WDR: weighed dietary record
PUFA: polyunsaturated fatty acid
PC: Pearson's correlation coefficient
SR: Spearman's rank correlation coefficient

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INTRODUCTION

Food frequency questionnaires (FFQs) have long been a popular choice as a dietary assessment tool in large-scale epidemiological investigations including cohort studies because food frequency methods are inexpensive and less laborious for both participants and research staff compared with short-term recall or dietary records. In addition, FFQs can cover average long-term diets over months or years, which is conceptually more important in regard to lifestyle-related diseases than are intakes on a few specific days.[1] Therefore, we applied a 47-item FFQ[2] to three cohort studies: the Japan Multi-institutional Collaborative Cohort (J-MICC) Study,[3,4] the Yamagata Molecular Epidemiological Cohort Study,[5] and the Tsuruoka Metabolomics Cohort Study.[6]

Food frequency methods depend on respondents' cognition and recall, so measurement errors in dietary intake are inevitable.[1,7] Therefore, the reproducibility and validity of FFQs need to be examined and should be checked at several levels, that is, foods, food groups, and nutrients and energy, the intakes of which are associated with health-related outcomes.

Regarding the consumption of food groups, we have reported the reproducibility and validity of the 47-item FFQ in the study areas of the above-mentioned three cohort studies throughout Japan, except for the Hokkaido and Chugoku districts.[8] For nutrient intakes and energy, however, a study on reproducibility[9] and validity[10,11] was conducted exclusively in the Aichi area of central Japan, where the questionnaire was originally developed and used. Because this FFQ uses a procedure to estimate nutrient intakes from a few specific foods selected by regression analysis, certain micronutrients may have regression coefficients associated with only three to six foods. The regression equations, however, may not be so robust and may vary among areas, even in Japan. To our knowledge, no other FFQs in Japan use regression analysis to estimate nutrient intakes. Even for FFQs that apply contribution analysis to estimate nutrient intakes from a large number of food items on a food list, validity is reassessed when the target population or area changes.[12-14] Therefore, the need for validation studies is even greater for FFQs that use regression analysis.

Given this background, we aimed to examine the reproducibility and validity of the FFQ for nutrient and energy intakes in the study areas of the cohort studies for a more appropriate interpretation of findings from the cohort studies based on the intakes estimated using the FFQ.

METHODS

Characteristics and recruitment of the participants

To ensure that the age distribution in this validation study matched that of the J-MICC Study, volunteers aged 35–69 years were recruited from each area. The recruitment methods varied by area. In areas that collaborated with health checkup institutions, attendees were invited to participate in the dietary survey. Additionally, in some areas, participants who had already taken part in the baseline survey of the J-MICC Study were invited by mail to join the dietary survey. Therefore, participants in the dietary survey did not necessarily belong to the cohort population.

The J-MICC Study, launched in 2005, is a cohort study designed to examine gene–environment interactions in lifestyle-related diseases, particularly cancers. Participants in the J-MICC Study, aged 35–69 years, were enrolled from the community through a variety of methods, including leaflets distributed to individuals who had received a health checkup and invitation letters mailed to community residents.

The validity study for the FFQ began in Amami in 2009, followed by the Fukuoka area. FFQ and weighed dietary record (WDR) data were collected from 32 participants in each area (Figure 1). For the remaining 11 areas, we recalculated the sample size to prevent age bias in 2011. We ensured that each area had at least 12 participants of each gender, with a minimum of three participants in each of the following groups: men aged 35–49 years, men aged 50–69 years, women aged 35–49 years, and women aged 50–69 years. The sample size was designed to include a statistically sufficient number of participants; further details are provided elsewhere.[8] Ultimately, we recruited 372 individuals aged 35–69 years from 13 areas across three cohort studies for a dietary survey conducted from 2009 to 2013. All participants were healthy volunteers

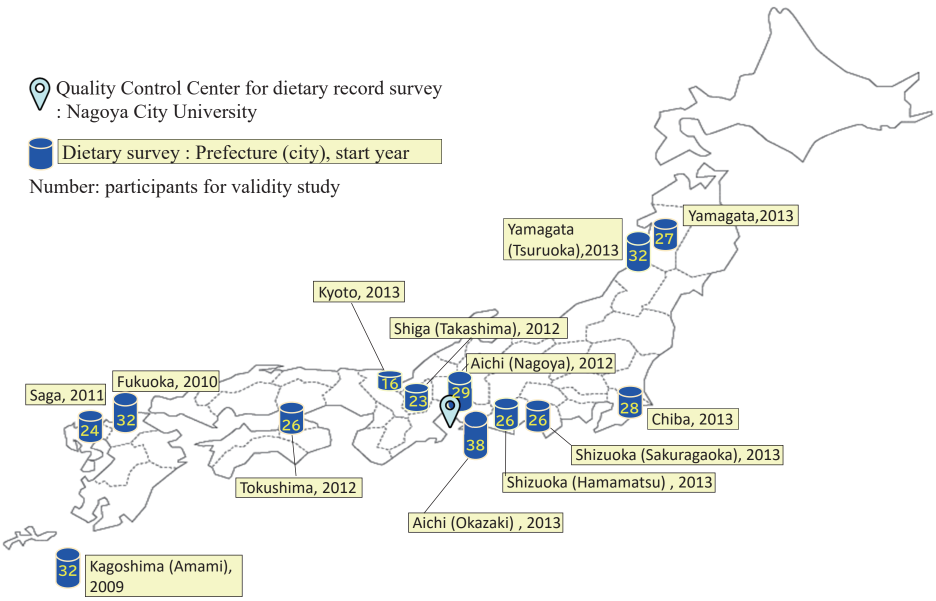

Fig. 1 Study areas and schedule of the dietary surveys for validation of the FFQ
The height of the cylinders indicates the number of participants. The dietary survey first began in Amami in 2009, followed by Fukuoka.
FFQ: food frequency questionnaire

living in the community, not affiliated with hospitals or facilities, and no exclusion criteria were imposed based on disease. To observe between-individual variation, only one participant per household was included.

Study schedule and design of reproducibility and validation

Validity and reproducibility were assessed as illustrated in Figure 2. At the beginning of the survey, we collected data on the participants' age, sex, height, weight, and physical activity level using a self-administered questionnaire, along with the first FFQ (FFQ1). Participants then completed four 3-day WDRs (WDR1–WDR4) at 3-month intervals. At 2 months after the last dietary record (WDR4), participants were asked to complete the second FFQ (FFQ2) to assess reproducibility by comparing it with FFQ1. In the Fukuoka area, however, only FFQ1 was administered, as the study focused solely on evaluating validity and did not include FFQ2 for a reproducibility assessment. The FFQs were validated by comparing the dietary intakes estimated by FFQ1 with those derived from the WDRs as a reference. Details of the FFQ and WDRs are described below.

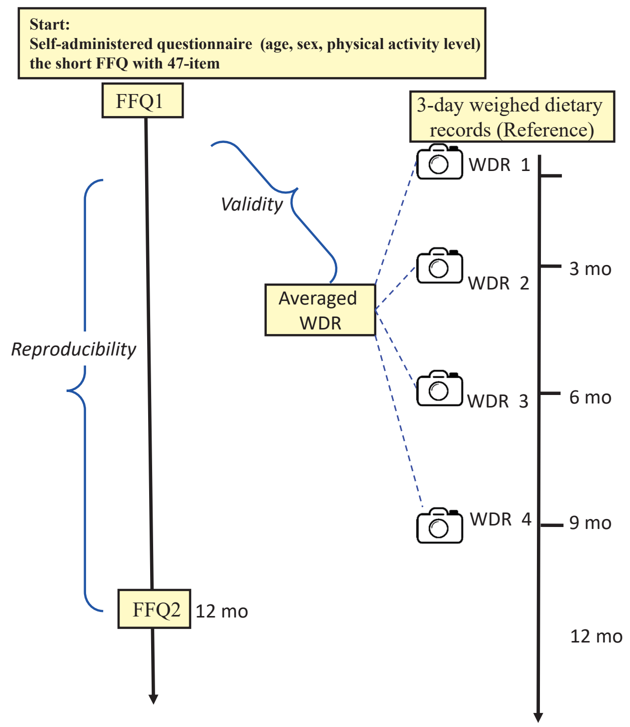

Fig. 2 Design of the reproducibility and validity study for the 47-item short FFQ
The participants initially completed the first FFQ (FFQ1). Four nonconsecutive 3-day weighed dietary records (WDRs) using photographs were then conducted at 3-month intervals. The responders were asked to answer the second FFQ (FFQ2) at 2 months after the last WDR. Photographs were not required in Amami or Fukuoka. The FFQ2 was not conducted in the Fukuoka area.
FFQ: food frequency questionnaire

Dietary intake using the 47-item FFQ

The self-administered FFQ includes questions on the average frequency of consumption during the past year, with eight possible responses: almost never, 1–3 times per month, 1–2 times per week, 3–4 times per week, 5–6 times per week, once per day, twice per day, and ≥ 3 times per day. These responses were assigned discrete values of 0, 0.1, 0.2, 0.5, 0.8, 1, 2, and 3, respectively, representing the frequency of intake per day, with one month consisting of 28 days.[2] The FFQ does not include any questions on the usual portion size for 43 food items, so we applied the sex-specific standard portion sizes based on WDRs in a population in Aichi Prefecture.[2] However, portion sizes are requested for three kinds of major staple foods in Japan (ie, rice, bread, and noodles). For alcoholic beverages, the frequency per week or month and the average amount consumed per occasion were asked for 10 items on the questionnaire: sake, *shochu* (Japanese liquor), *shochu* highball, large bottled beer (633 mL), middle bottled beer (500 mL), 350 mL canned beer, 250 mL canned beer, single whiskey, double whiskey, and wine.

Daily consumption for each food item was computed by multiplying the portion size by the intake score. The energy and nutrient intakes were estimated as Σ (frequency of consumption [intake score]) × (portion size in grams) × (nutrient content per 100 g)/100 × the regression coefficient of that food item for energy or the nutrient + a unique intercept for energy or the nutrient.[10] The sigma indicates the sum over all the food items selected by the regression models. The coefficients and intercepts were determined by regressing energy/nutrient intake on intakes from all the foods in the questionnaire with statistical selection in the previous study.[2] Due to the selection of explanatory variables in the regression analysis, the number of foods that contribute to the estimation of intake varies among energy or nutrients. Some nutrients were estimated based on the frequency consumption of only a few food items in the FFQ (eg, three food items for both carotene and *n*-3 highly polyunsaturated fatty acids [PUFAs]).

Reference method

Nonconsecutive 3-day WDRs were conducted including one weekend day at 3-month intervals over four seasons; that is, 12-day WDRs were collected. Participants were asked to record the intakes of all foods, dishes, and drinks using a notebook and mobile photography. The surveys in Amami and Fukuoka, which were conducted by well-trained registered dietitians, also required participants to record their meals and dishes using a WDR in a notebook. However, mobile photography was not required in these two areas. The Quality Control Center for dietary surveys, which has been set up at Nagoya City University (also the developer of the short FFQ) since 2011, handled the training of registered dietitians, confirmed the accuracy of the WDRs, and checked for food code errors. In each season, registered dietitians thoroughly inquired about the WDRs via phone or e-mail. Specifically, during the first season's dietary survey, face-to-face interviews were conducted in some areas because the Quality Control Center recommended real-time, interactive methods such as interviews or phone calls to communicate with the participants. However, considering that detailed responses might not be obtained depending on the participants' knowledge about their diet or level of interest, alternative one-way methods such as e-mail were also permitted with the decision of the registered dietitians in each area. The procedures for the dietary record surveys are detailed in a previous paper.[15] Data from all 13 areas were retrieved using a unified, standardized data-checking algorithm, and two research dietitians (N.I. and C.G.) from the Quality Control Center checked and corrected any suspicious data (such as outliers and missing data for seasonings).[16,17]

Statistical analysis

Body mass index was calculated using the following formula: (body weight [kg])/(height

[m])[2]. Energy intake by WDRs and FFQs were estimated using the Standard Tables of Food Composition in Japan, 5th edition.[18] The targets for the present validation study were energy intakes and 26 macro- and micronutrients, including protein, fat (saturated fatty acids [SFAs], mono-unsaturated fatty acids [MUFAs], PUFAs, *n*-6 PUFAs, *n*-3 PUFAs, *n*-3 highly unsaturated fatty acids [HUFAs], and cholesterol), carbohydrates, vitamins (carotene and retinol activity equivalents, thiamin, riboflavin, folate, ascorbic acid, vitamin D, and alpha-tocopherols) and minerals (calcium and iron), and three added nutrients of interest, including sodium, potassium, and the ratio of sodium to potassium (Na/K), which were not originally target nutrients of the FFQ.

Comparison of dietary intakes. In considering the distribution of dietary intakes, the means and standard deviations of the FFQ1 and WDRs were calculated separately for men and women. The ratio of within-individual variation to between-individual variation was calculated because within-individual variation is a source of errors in dietary assessments. The residual method was performed to adjust the energy intake.[1]

Correlation. We evaluated the reproducibility for each dietary intake between the FFQ1 and FFQ2 using Pearson's correlation coefficients (PCs), energy-adjusted PCs, Spearman's rank correlation coefficients (SRs), and energy-adjusted SRs. The intake was $\log_e$-transformed for PCs but not for SRs. Validity was evaluated using the same coefficients between the FFQ1 and WDRs. The de-attenuated PCs and SRs indicated correlations adjusted for random within-individual errors from the usual intake of each nutrient.[1,19] The within-individual variations between the four 3-day WDRs were considered in the analysis.

Agreement of cross-classification. We examined the categorical agreement of estimated intakes between the FFQ1 and FFQ2 for reproducibility. For validity, the categorical agreement of calculated intakes was examined between the FFQ1 and WDRs. We computed the number of participants classified into the same, adjacent, and extreme categories by cross-classification according to quintile.

Ethical considerations

The protocol of the present study was approved by the ethical review board of Aichi Cancer Center (No. 3-50, 2011) before the study began. Written informed consent was obtained from all participants after they received explanations about the purpose and methods of the present study.

RESULTS

The baseline characteristics of the participants are shown in Table 1. Of the initial participants (185 men and 187 women), 177 men and 182 women completed both FFQs, except in the Fukuoka area, where the FFQ2 was not administered (n = 16 for both men and women), and all the WDRs were included in the analyses for validity. Figure 1 shows a map of the study areas and the start year of the validity study. The height of the cylinders indicates the number of participants. The reasons for exclusions were as follows: eight participants failed to complete the WDRs owing to their busy schedule, one retracted her consent, three recorded their diet for more than 12 days, and one other than the Fukuoka respondents did not fill in both the FFQ1. In addition, two men and five women who left many missing values in the FFQ2 were excluded from the analysis of reproducibility. Eventually, reproducibility was examined in the 159 men and 161 women who completed both the FFQ1 and the FFQ2.

The mean nutrient and energy intakes were compared between the WDRs and the FFQ1 (Table 2). Energy was underestimated by the FFQ by 13% for men and 11% for women compared with the WDR values. For most nutrients, significant differences ($p < 0.01$) between the FFQ

Table 1 Baseline characteristics of the participants for the reproducibility and validity studies

	Men		Women	
	Mean	(SD)	Mean	(SD)
Participants for the validity study				
WDR vs FFQ1	n = 177		n = 182	
Age (years)	53.0	(9.3)	52.3	(8.8)
BMI (kg/m^2)	23.5	(3.1)	22.1	(3.7)
Participants for the reproducibility study[a]				
FFQ1 vs FFQ2	n = 159		n = 161	
Dietary habits[b]	n = 132	100%	n = 137	100%
Skipping breakfast				
3 times/week or less	10	8%	6	4%
4–6 times/week	11	8%	9	7%
Every day	111	84%	122	89%
Between-meal snacks				
Every day	29	22%	74	54%
Sometimes	70	53%	58	42%
Never	33	25%	5	4%
Alcohol drinking				
Current	104	79%	77	56%
Former	1	1%	2	1%
Never	27	20%	58	42%
Intention to reduce intakes of salt, energy, sugar, and fat				
1. Salt (yes)	64	48%	75	59%
2. Energy (yes)	53	40%	70	55%
3. Sugar (yes)	50	38%	50	42%
4. Fat (yes)	61	46%	76	58%

WDR: four nonconsecutive 3-day weighed dietary records at intervals of 3 months (12 days)
FFQ1: the first food frequency questionnaire at baseline
FFQ2: the second FFQ 1 year after the FFQ1
SD: standard deviation
BMI: body mass index
[a] FFQ2 was not conducted in the Fukuoka area. The subjects who completed FFQ1, FFQ2, and WDRs were included in the reproducibility study.
[b] Data on dietary habits were not provided for Fukuoka, Amami, or Shizuoka (Sakuragaoka).

and the WDR were observed by a paired *t*-test, and the differences were largest for sodium among both men and women. The correlation between usual intake, as estimated by recalling the previous year in the FFQ2 and FFQ1, showed SRs for energy intake of 0.67 for men and 0.71 for women. All of the energy-adjusted SRs between the FFQ1 and the FFQ2 exceeded 0.5, except those for *n*-3 PUFA for men (0.49; Table 3).

Table 2 Selected nutrient intakes according to weighed dietary records (WDRs) and the first FFQ (FFQ1) in men and women

	Men (n = 177)				Women (n = 182)			
	WDR	FFQ1	%		WDR	FFQ1	%	
Nutrients (unit/d)	Mean (SD)	Mean (SD)	difference	*p*-value	Mean (SD)	Mean (SD)	difference	*p*-value
Energy (kcal)	2,240 (359)	1,945 (385)	–13	**	1,740 (265)	1,543 (226)	–11	**
Protein (g)	81.1 (15)	57.2 (11)	–30	**	66.0 (12)	52.0 (9)	–21	**
Fat (g)	66.7 (15)	44.5 (12)	–33	**	55.6 (12)	46.7 (10)	–16	**
SFA (g)	17.3 (5)	11.1 (3)	–36	**	15.1 (4)	11.9 (3)	–21	**
MUFA (g)	23.9 (6)	16.6 (4)	–31	**	19.8 (5)	17.1 (4)	–13	**
PUFA (g)	15.9 (4)	13.4 (3)	–16	**	12.8 (3)	13.7 (3)	7	**
n-3 PUFA (mg)	2,785 (758)	2,274 (544)	–18	**	2,218 (613)	2,282 (573)	3	
n-6 PUFA (mg)	12,791 (2,970)	11,343 (3,025)	–11	**	10,285 (2,404)	11,490 (3,013)	12	**
n-3 HUFA (mg)	613 (384)	484 (328)	–21	**	473 (289)	701 (334)	48	**
Cholesterol (mg)	377 (106)	244 (63)	–35	**	306 (84)	250 (63)	–18	**
Carbohydrate (g)	296 (56)	282 (69)	–5	**	233 (40)	210 (40)	–10	**
SDF (g)	3.5 (1.2)	2.0 (0.6)	–43	**	3.2 (0.9)	2.2 (0.6)	–33	**
IDF (g)	11.4 (3.9)	7.6 (2.1)	–33	**	10.4 (2.9)	8.7 (2.1)	–16	**
TDF (g)	15.6 (5.3)	10.7 (3.)	–31	**	14.2 (3.9)	11.9 (3.)	–16	**
Sodium (mg)	4,436 (907)	1,870 (507)	–58	**	3,632 (796)	1,765 (458)	–51	**
Potassium (mg)	2,934 (752)	2,156 (488)	–27	**	2,642 (602)	2,283 (507)	–14	**
Na/K	1.6 (0.3)	1.0 (0.4)	–38	**	1.4 (0.3)	0.8 (0.3)	–42	**
Calcium (mg)	539 (161)	500 (131)	–7	**	525 (151)	560 (148)	7	**
Iron (mg)	9.0 (2.2)	7.1 (1.9)	–22	**	7.9 (2.0)	7.5 (1.9)	–5	**
Beta-carotene Eq (μg)	959 (435)	987 (507)	3	**	949 (495)	1,071 (459)	13	
Retinol activity Eq (μg)	3,977 (2,087)	3,033 (1,240)	–24		3,888 (1,526)	3,867 (1,701)	–1	**
Vitamin D (μg)	8 (4)	7 (3)	–12	**	7 (3)	7 (3)	6	
Alpha-tocopherols Eq (mgRE)	10 (2)	8 (2)	–18	**	9 (2)	9 (2)	1	
Thiamin (mg)	1.1 (0.3)	0.7 (0.1)	–42	**	0.9 (0.2)	0.7 (0.1)	–28	**
Riboflavin (mg)	1.4 (0.4)	1.1 (0.3)	–26	**	1.3 (0.3)	1.1 (0.2)	–12	**
Folate (μg)	403 (127)	317 (96)	–21	**	370 (109)	374 (126)	1	
Ascorbic acid (mg)	129 (59)	85 (29)	–35	**	122 (42)	106 (38)	–13	**
Energy from alcohol (kcal)[a]	105 (120)	330 (117)	213		30 (70)	26 (63)	–12	

SFAs: saturated fatty acids
MUFAs: monounsaturated fatty acids
PUFAs: polyunsaturated fatty acids
HUFAs: highly unsaturated fatty acids
TDF: total dietary fiber
SDF: soluble dietary fiber
IDF: insoluble dietary fiber
WDR: four nonconsecutive 3-day weighed dietary records at intervals of 3 months (12 days)
FFQ1: the first food frequency questionnaire at baseline
FFQ2: the second FFQ 1 year after the FFQ1
SD: standard deviation
Na/K: ratio of sodium to potassium
% difference: The percentage difference was calculated as (FFQ1 − WDR)/WDR × 100.
P-values < 0.01, indicated by **, were determined using a paired *t*-test.
[a] In the FFQ1, 21% (38/177) of men and 49% (90/182) of women reported drinking habits as “never”.

Table 3 Correlation coefficients between the FFQ1 and FFQ2 for reproducibility in men and women

Nutrients	Men (n = 159)				Women (n = 161)			
	PC		SR		PC		SR	
	Log_e-transformed	Energy-adjusted	Crude	Energy-adjusted	Log_e-transformed	Energy-adjusted	Crude	Energy-adjusted
Energy	0.76		0.67		0.69		0.71	
Protein	0.70	0.71	0.65	0.65	0.70	0.62	0.69	0.62
Fat	0.64	0.66	0.64	0.66	0.70	0.65	0.67	0.63
SFA	0.73	0.70	0.71	0.69	0.73	0.70	0.77	0.73
MUFA	0.54	0.53	0.54	0.54	0.68	0.64	0.66	0.61
PUFA	0.58	0.55	0.60	0.56	0.65	0.60	0.66	0.60
n-3 PUFA	0.52	0.51	0.50	0.49	0.67	0.61	0.61	0.54
n-6 PUFA	0.56	0.55	0.57	0.55	0.63	0.58	0.63	0.56
n-3 HUFA	0.65	0.64	0.68	0.63	0.68	0.65	0.68	0.65
Cholesterol	0.71	0.71	0.73	0.72	0.64	0.60	0.62	0.60
Carbohydrate	0.80	0.81	0.73	0.75	0.74	0.76	0.72	0.71
SDF	0.72	0.73	0.69	0.70	0.73	0.72	0.71	0.73
IDF	0.71	0.73	0.71	0.72	0.75	0.74	0.71	0.72
TDF	0.73	0.74	0.72	0.73	0.73	0.71	0.69	0.69
Sodium	0.65	0.65	0.63	0.63	0.64	0.62	0.62	0.60
Potassium	0.73	0.70	0.68	0.66	0.76	0.72	0.72	0.68
Na/K	0.62	0.60	0.59	0.58	0.68	0.67	0.65	0.64
Calcium	0.73	0.72	0.73	0.72	0.77	0.75	0.79	0.75
Iron	0.77	0.76	0.78	0.78	0.76	0.75	0.73	0.74
Beta-carotene Eq	0.69	0.68	0.67	0.65	0.72	0.69	0.69	0.67
Retinol activity Eq	0.62	0.62	0.61	0.60	0.67	0.64	0.63	0.60
Vitamin D	0.65	0.64	0.67	0.63	0.68	0.64	0.65	0.66
Alpha-tocopherols Eq	0.55	0.54	0.58	0.56	0.68	0.62	0.65	0.61
Thiamin	0.60	0.60	0.59	0.60	0.67	0.64	0.67	0.64
Riboflavin	0.76	0.76	0.76	0.76	0.77	0.74	0.78	0.77
Folate	0.70	0.69	0.70	0.71	0.71	0.70	0.70	0.68
Ascorbic acid	0.73	0.73	0.73	0.73	0.71	0.71	0.69	0.69
Energy from alcohol	0.84	0.83	0.86	0.84	0.89	0.88	0.89	0.74
Median	0.70	0.69	0.67	0.66	0.70	0.67	0.69	0.66
Minimum	0.52	0.51	0.50	0.49	0.63	0.58	0.61	0.54
Maximum	0.84	0.83	0.86	0.84	0.89	0.88	0.89	0.77

SFAs: saturated fatty acids
MUFAs: monounsaturated fatty acids
PUFAs: polyunsaturated fatty acids
HUFAs: highly-unsaturated fatty acids
TDF: total dietary fiber
SDF: soluble dietary fiber
IDF: insoluble dietary fiber
FFQ1: the first food frequency questionnaire at baseline
FFQ2: the second FFQ 1 year after the FFQ1
PC: Pearson's correlation coefficient
SR: Spearman's rank correlation coefficient
Na/K: ratio of sodium to potassium

When intakes estimated by the FFQ1 were compared with those based on the WDRs (Table 4), the median of the de-attenuated SRs over energy and all the nutrients were 0.35 in men and 0.43 in women. The coefficients were 0.25 (p < 0.001) or higher for energy and almost all the nutrients, but were low for the following nutrients: 0.15 for Na/K, 0.13 for thiamin, 0.19 for PUFA and *n*-6 PUFA, 0.22 for protein, and 0.23 for alpha-tocopherol in men, and 0.20 for protein and 0.24 for thiamin in women.

Table 4 Correlation coefficients between WDRs and the first FFQ (FFQ1) for validity in men and women

	FFQ1 vs WDR among men (n = 177)						FFQ1 vs WDR among women (n = 182)					
	PC			SR			PC			SR		
Nutrients	Energy-adjusted	De-attenuated	95% CI	Energy-adjusted	De-attenuated	95% CI	Energy-adjusted	De-attenuated	95% CI	Energy-adjusted	De-attenuated	95% CI
Energy	0.37	0.40	(0.25–0.52)	0.32	0.32	(0.19–0.46)	0.37	0.41	(0.26–0.53)	0.33	0.33	(0.20–0.47)
Protein	0.24	0.27	(0.11–0.42)	0.21	0.22	(0.07–0.38)	0.17	0.20	(0.03–0.35)	0.18	0.20	(0.04–0.36)
Fat	0.30	0.33	(0.18–0.47)	0.26	0.28	(0.13–0.43)	0.44	0.50	(0.36–0.62)	0.44	0.48	(0.35–0.62)
SFA	0.32	0.36	(0.20–0.49)	0.32	0.34	(0.20–0.49)	0.45	0.51	(0.37–0.63)	0.46	0.50	(0.37–0.63)
MUFA	0.28	0.31	(0.15–0.45)	0.27	0.28	(0.14–0.44)	0.36	0.40	(0.25–0.54)	0.35	0.37	(0.24–0.52)
PUFA	0.17	0.21	(0.03–0.38)	0.17	0.19	(0.02–0.37)	0.35	0.42	(0.25–0.57)	0.35	0.41	(0.26–0.57)
n-3 PUFA	0.21	0.28	(0.08–0.45)	0.21	0.27	(0.08–0.45)	0.33	0.42	(0.24–0.57)	0.34	0.42	(0.25–0.59)
n-6 PUFA	0.18	0.22	(0.04–0.38)	0.16	0.19	(0.02–0.36)	0.28	0.35	(0.17–0.50)	0.29	0.34	(0.18–0.51)
n-3 HUFA	0.32	0.42	(0.23–0.58)	0.34	0.43	(0.26–0.60)	0.43	0.56	(0.37–0.70)	0.44	0.56	(0.39–0.72)
Cholesterol	0.29	0.33	(0.17–0.48)	0.32	0.36	(0.21–0.52)	0.37	0.46	(0.29–0.60)	0.38	0.44	(0.29–0.60)
Carbohydrate	0.46	0.49	(0.36–0.61)	0.42	0.43	(0.31–0.57)	0.41	0.45	(0.31–0.57)	0.37	0.39	(0.26–0.54)
SDF	0.57	0.61	(0.49–0.70)	0.58	0.60	(0.50–0.71)	0.42	0.46	(0.32–0.58)	0.42	0.44	(0.32–0.58)
IDF	0.56	0.59	(0.47–0.68)	0.57	0.58	(0.48–0.69)	0.39	0.42	(0.28–0.54)	0.39	0.40	(0.28–0.54)
TDF	0.55	0.58	(0.46–0.68)	0.54	0.54	(0.44–0.66)	0.45	0.48	(0.35–0.59)	0.45	0.47	(0.35–0.60)
Sodium	0.22	0.24	(0.08–0.40)	0.21	0.23	(0.07–0.39)	0.31	0.35	(0.19–0.49)	0.30	0.33	(0.19–0.49)
Potassium	0.35	0.36	(0.22–0.49)	0.33	0.33	(0.20–0.47)	0.35	0.37	(0.23–0.50)	0.36	0.36	(0.24–0.50)
Na/K	0.15	0.16	(0.00–0.31)	0.15	0.15	(0.00–0.31)	0.28	0.31	(0.15–0.45)	0.26	0.28	(0.13–0.43)
Calcium	0.59	0.64	(0.53–0.74)	0.60	0.63	(0.53–0.74)	0.53	0.57	(0.45–0.68)	0.53	0.55	(0.44–0.67)
Iron	0.43	0.47	(0.33–0.59)	0.43	0.45	(0.33–0.59)	0.51	0.55	(0.43–0.66)	0.51	0.54	(0.43–0.66)
Beta-carotene Eq	0.41	0.46	(0.32–0.59)	0.41	0.44	(0.31–0.58)	0.38	0.46	(0.30–0.60)	0.37	0.43	(0.28–0.59)
Retinol activity Eq	0.24	0.29	(0.11–0.45)	0.22	0.25	(0.09–0.42)	0.39	0.53	(0.33–0.68)	0.38	0.49	(0.32–0.66)
Vitamin D	0.28	0.34	(0.16–0.50)	0.31	0.37	(0.21–0.55)	0.43	0.54	(0.37–0.68)	0.46	0.56	(0.41–0.71)
Alpha-tocopherols Eq	0.22	0.25	(0.09–0.41)	0.21	0.23	(0.07–0.39)	0.34	0.40	(0.23–0.54)	0.32	0.37	(0.22–0.53)
Thiamin	0.10	0.12	(–0.06–0.29)	0.11	0.13	(–0.04–0.30)	0.20	0.23	(0.06–0.39)	0.21	0.24	(0.08–0.41)
Riboflavin	0.48	0.52	(0.39–0.64)	0.48	0.50	(0.39–0.64)	0.46	0.51	(0.38–0.63)	0.47	0.50	(0.38–0.63)
Folate	0.43	0.47	(0.33–0.59)	0.44	0.47	(0.35–0.60)	0.37	0.42	(0.27–0.55)	0.37	0.40	(0.27–0.54)
Ascorbic acid	0.56	0.59	(0.48–0.69)	0.56	0.58	(0.48–0.69)	0.46	0.52	(0.37–0.64)	0.46	0.50	(0.37–0.63)
Energy from alcohol	0.79	0.83	(0.76–0.88)	0.76	0.79	(0.72–0.86)	0.73	0.79	(0.70–0.85)	0.66	0.71	(0.62–0.80)
Median	0.32	0.36		0.32	0.35		0.39	0.46		0.38	0.43	
Minimum	0.10	0.12		0.11	0.13		0.17	0.20		0.18	0.20	
Maximum	0.79	0.83		0.76	0.79		0.73	0.79		0.66	0.71	

SFAs: saturated fatty acids
MUFAs: monounsaturated fatty acids
PUFAs: polyunsaturated fatty acids
HUFAs: highly-unsaturated fatty acids
TDF: total dietary fiber
SDF: soluble dietary fiber
IDF: insoluble dietary fiber
WDR: four nonconsecutive 3-day weighed dietary records at intervals of 3 months (12 days)
FFQ1: the first food frequency questionnaire at baseline
PC: Pearson's correlation coefficient
SR: Spearman's rank correlation coefficient
Na/K: ratio of sodium to potassium
De-attenuated PCx = observed PCx × $(1 + \lambda x/n)^{0.5}$, where λx is the ratio of within to between-individual variance for dietary intake x, and n is the number of dietary surveys = 4. Rank of dietary intakes was transformed using the probit function for SR[19].

In the cross-classification of FFQ1 and FFQ2 estimates by quintile, 81% of men and 79% of women (as medians over energy and all nutrients) were grouped into the same and adjacent categories by the two questionnaires (Table 5-a and 5-b). The corresponding percentages for validation comparing the FFQ1 estimates and WDR intakes were 63% in men and 66% in women. Extreme disagreement (cross-classification into the lowest and highest quintiles) was rare for energy and most nutrients, with medians of 3% for men and women. However, higher proportions were found for Na/K (8%) and thiamin (8%) in men, and alpha-tocopherols (7%) in women.

Table 5-a Comparison of FFQ1 with FFQ2 and FFQ1 with 12-day WDRs for energy-adjusted nutrition intake, based on cross-classification by quintile (%) in men

	FFQ1 vs FFQ2 (n = 159)			FFQ1 vs WDR (n = 177)		
	Same category	Same and adjacent categories	Extreme category	Same category	Same and adjacent categories	Extreme category
Men						
Energy	43	79	0	27	59	2
Protein	40	76	1	25	54	5
Fat	42	82	0	25	60	3
SFA	48	82	3	31	68	4
MUFA	42	77	3	28	60	6
PUFA	36	75	2	26	60	5
n-3 PUFA	36	74	3	26	56	5
n-6 PUFA	36	73	1	27	56	3
n-3 HUFA	37	77	1	24	60	4
Cholesterol	55	86	1	29	62	2
Carbohydrate	47	86	1	30	69	3
SDF	48	82	1	27	76	2
IDF	44	87	2	33	71	2
TDF	44	84	1	33	71	2
Sodium	47	81	1	25	62	7
Potassium	40	81	0	27	64	5
Na/K	35	75	0	29	58	8
Calcium	44	86	1	35	76	2
Iron	51	86	0	34	72	2
Beta-carotene Eq	48	79	1	29	66	3
Retinol activity Eq	48	81	3	24	57	4
Vitamin D	42	79	1	23	64	4
Alpha-tocopherols Eq	37	75	1	20	56	4
Thiamin	38	75	1	25	58	8
Riboflavin	48	86	0	35	76	3
Folate	43	84	1	26	67	3
Ascorbic acid	43	84	1	34	70	1
Energy from alcohol	60	92	1	50	88	1
Median	43	81	1	27	63	3
Range	(35–60)	(73–92)	(0–3)	(20–50)	(54–88)	(1–8)

SFAs: saturated fatty acids
MUFAs: monounsaturated fatty acids
PUFAs: polyunsaturated fatty acids
HUFAs: highly-unsaturated fatty acids
TDF: total dietary fiber
SDF: soluble dietary fiber
IDF: insoluble dietary fiber
WDR: four nonconsecutive 3-day weighed dietary records at intervals of 3 months (12 days)
FFQ1: the first food frequency questionnaire at baseline
FFQ2: the second food frequency questionnaire
Na/K: ratio of sodium to potassium

Table 5-b Comparison of FFQ1 with FFQ2 and FFQ1 with 12-day WDRs for energy-adjusted nutrition intake, based on cross-classification by quintile (%) in women

	FFQ1 vs FFQ2 (n = 161)			FFQ1 vs WDR (n = 182)		
	Same category	Same and adjacent categories	Extreme category	Same category	Same and adjacent categories	Extreme category
Women						
Energy	44	84	1	29	60	3
Protein	41	78	2	23	54	5
Fat	36	76	1	28	69	3
SFA	44	84	1	31	66	3
MUFA	40	75	2	27	61	3
PUFA	38	75	0	31	64	3
n-3 PUFA	35	76	2	28	63	4
n-6 PUFA	34	76	1	31	58	3
n-3 HUFA	42	78	1	27	65	1
Cholesterol	39	75	1	29	70	1
Carbohydrate	43	83	0	24	63	3
SDF	44	86	1	32	67	3
IDF	44	84	0	34	68	3
TDF	43	81	0	32	70	3
Sodium	44	76	1	27	64	3
Potassium	38	79	0	27	68	5
Na/K	42	79	0	32	65	6
Calcium	45	89	1	34	73	2
Iron	42	84	0	37	67	1
Beta-carotene Eq	39	80	0	26	64	5
Retinol activity Eq	39	76	0	24	66	4
Vitamin D	40	78	1	26	71	3
Alpha-tocopherols Eq	36	80	1	32	63	7
Thiamin	40	78	2	24	60	6
Riboflavin	44	89	1	31	71	1
Folate	43	82	1	28	63	4
Ascorbic acid	39	83	0	26	72	2
Energy from alcohol	n/a	n/a	n/a	43	80	1
Median	42	79	1	29	66	3
Range	(34–45)	(75–89)	(0–2)	(23–43)	(54–80)	(1–7)

SFAs: saturated fatty acids
MUFAs: monounsaturated fatty acids
PUFAs: polyunsaturated fatty acids
HUFAs: highly-unsaturated fatty acids
TDF: total dietary fiber
SDF: soluble dietary fiber
IDF: insoluble dietary fiber
WDR: four nonconsecutive 3-day weighed dietary records at intervals of 3 months (12 days)
FFQ1: the first food frequency questionnaire at baseline
FFQ2: the second food frequency questionnaire
Na/K: ratio of sodium to potassium
n/a: not available because alcohol energy was 0 calories for 72 of the 161 women participants in FFQ1 and 76 in FFQ2, respectively

DISCUSSION

In the present study, the FFQ with 47 food items was well reproducible and showed acceptable validity. The medians of the de-attenuated SRs for validity were 0.35 in men and 0.43 in women, which are comparable to other FFQs that have been developed and validated in Japan.[20-23] However, the validity was low (de-attenuated SR < 0.25) for some nutrients: Na/K, thiamin, protein, and alpha-tocopherol in men, and protein and thiamin in women.

For men, the validity was high for carbohydrates and dietary fiber supplied by staple foods. This may be because the FFQ has only 47 items, and the frequencies for staple foods (rice, bread, and noodles) were asked in respect to three times at breakfast, lunch, and dinner, as well as to each portion size. In addition, the consumption of staple food showed wide variation between individuals, so it was easy to categorize the participants. For women, the correlation coefficients were high for fat, SFAs, and HUFAs.

The reason for the low validity of the Na to K ratio may be that sodium and potassium were not targets for estimation when the FFQ was originally developed, and therefore, it does not include questions about cooking methods or seasonings, which are important to estimate sodium intake. The validity was extremely low for protein and thiamin for both men and women. According to a previous validity study using the same FFQ for Amami residents, the PC for protein was 0.56 for 37 women and thus higher in the Amami study.[24] That study reported many women with higher alcohol consumption, and greater variability would be expected in the dietary intake of protein. According to Ruf et al,[25] the dietary habits of heavy drinkers differ from those of nondrinkers, with heavy drinkers reported to have a low dietary fiber and carbohydrate energy ratio. Protein intake showed a broad distribution in the group that included some heavy drinkers, while the protein energy ratio distribution in this group was narrow. In the present study, the 25th and 75th percentiles of the protein energy ratio observed as "real intake" using dietary records were 12% and 13%, respectively, which may have resulted in a decreased categorizing ability of the FFQ. Overall, the reason for the low validity for total protein in the present study might be a small inter-individual variation. However, the validity of the food groups contributing protein is high. According to our previous FFQ validity study for food groups,[8] the correlation coefficients for rice, bread, and protein-rich foods, such as dairy products, meat, fish, and soybean paste, were high for both men and women. Despite the low correlation coefficients for protein, we assume that the present FFQ could mostly discriminate habitual dietary patterns. The low validity of thiamine in the present FFQ might be attributed to the limited number of food items selected by the regression analysis for estimating thiamine intake, such as fish eggs, ham/sausage, noodles, other vegetables, and meat and fish. While the validity for meat and fish was good,[8] it may be challenging to recall accurately the frequency of consumption of less frequently eaten foods like fish eggs or ham, which are associated with smaller portion sizes in men. Furthermore, our assessment of thiamine revealed a mean intake of 0.7 mg among men, with a standard deviation of 0.1 mg, indicating relatively low inter-individual variability compared with other nutrients. We believe that the validity of the FFQ is lower for nutrients with small inter-individual variability. The poor correlation coefficient for alpha-tocopherol in men is likely due to significant underreporting of the frequency of consumption of fried and sautéed foods. The validity of these food groups, specifically oils, showed a correlation coefficient of 0.38 for both men and women, with no significant gender difference. However, the median FFQ value for men was approximately 1.6 times lower than that of the WDRs, with a negative deviation in the quartile range. This suggests that reporting the intake frequency of oil-based food groups may be more difficult for men than for women.

We anticipated considerable differences in reproducibility and validity between the previous study in the Aichi area and the present study in wide areas in Japan. The differences might derive from not only variations in food culture between regions, but also the estimation methods for energy and nutrient intakes by the 47-item FFQ. The FFQ did not include foods frequently consumed in specified areas (eg, bitter melon, or *goya* in Amami, soba in Yamagata) for the estimation of nutrient intakes, which might have limited the reproducibility and validity in the population of the present study. Moreover, energy and nutrient intakes in the FFQ were computed using linear regression models. Because the models were developed based on WDRs in a population in Aichi Prefecture, they might not be valid in other regions of Japan. Evaluating the correlation coefficients for each area would indeed be insightful; however, due to the constraints of cost and manpower, the sample size in this report was limited. Even if we used the median PCs for the entire group (0.36 for 172 men and 0.46 for 182 women) to calculate the 95% confidence interval for each area, the results would not be informative, with ranges of –0.21 to 0.75 for men and –0.09 to 0.80 for women.

Reproducibility studies evaluating 25 nutrients, excluding sodium and potassium, were conducted in Aichi Prefecture as a previous study.[9] In that study, the median energy-adjusted SRs between two FFQs administered 1 year apart were 0.66 in men and 0.62 in women,[9] whereas in the present study, the corresponding medians were at a similar level or higher (0.66 in both men and women). A systematic review of reproducibility reported that correlation coefficients between two administrations of an FFQ typically range from 0.5 to 0.7.[26] In the present study, the correlation coefficients for reproducibility ranged from 0.49 to 0.89, which is considered to be sufficiently robust. Regarding validity, we compared the medians of the de-attenuated, energy-adjusted PCs among the reported nutrients between the two studies[10] and found similar values for men and higher indices for women; the coefficients were 0.37 and 0.36 in the previous and present studies, respectively, in men, and 0.31 and 0.46, respectively, in women. These findings suggest that the 47-item FFQ can be adopted in wide areas of Japan.

Regarding the Japanese FFQ with 40–60 food-item questions designed to estimate habitual dietary intakes other than those on our FFQ, four validation studies have been conducted since 2002.[20-23] Notably, the Brief Dietary Habit Questionnaire (BDHQ) reported by Kobayashi et al[20] showed excellent validity, with correlation coefficients exceeding 0.50 for 20 of the 27 selected nutrients.[27] The BDHQ is a self-administered questionnaire designed to assess the frequency of consumption of 58 foods and drinks, habitual cooking methods, and general eating habits. In the validation study, FFQ estimates were compared with dietary intakes from 16-day food record surveys over four seasons. In the present study, the FFQ was validated using 12-day dietary intakes, and correlation coefficients over 0.50 were achieved in six or seven of the 27 selected nutrients. Lee et al[21] reported the validity of a 40-item FFQ compared with 28-day dietary intakes and found eight nutrients with correlation coefficients over 0.50. According to a validity study by Ogawa et al[22] that compared the FFQ estimates with a 12-day dietary survey, four nutrients—energy, carbohydrate, calcium, and vitamin B_2—had correlation coefficients over 0.50, while the study by Tsubono et al,[23] which compared the intakes estimated by the FFQ with a 28-day dietary survey, included three nutrients: carbohydrates, calcium, and beta-carotene.

A major strength of the present study is that it included a sufficient number of participants from various areas in Japan. Some methodological issues described in our preceding report should be noted.[8] Especially, we did not select the subjects randomly from among participants in cohort studies, but rather, we recruited volunteers in the study areas. Those who were willing to complete laborious WDRs are more likely to be health conscious, so the reproducibility and validity of the FFQ among such individuals may differ compared with the other cohort members. In populations including individuals who skip meals or prefer junk food, as well as those with a habitual lack of vegetable consumption, significant inter-individual variability in dietary intake may be observed. Notably, the participants in the present study were generally more health conscious than such populations. Consequently, it is possible that the validity of the FFQ was underestimated.

This study has two notable limitations. First, when the validity study began in the Fukuoka and Amami areas, the participants were not required to provide photographs for the dietary record survey. As a result, less evidence is available regarding portion sizes in these areas compared with others. Second, the study in Fukuoka did not focus on reproducibility, as the FFQ2 was not administered. In these two and the remaining 11 areas, the dietary survey methods used were based on the food coding rules of the Japanese National Health and Nutritional Survey.[28] Although the standardized manuals used in Fukuoka and Amami were similar to those in other areas, the absence of photographs and the lack of the FFQ2 in Fukuoka present limitations in the design of the present study.

In conclusion, the 47-item FFQ was well reproducible and fairly to moderately valid for most of the targeted nutrients in the study areas of the three cohort studies where it was adopted. For the nutrients with low validity, that is, protein, Na/K, and thiamin in men, and protein in women, the intakes estimated by the FFQ and relevant findings in these cohort studies should be interpreted with caution.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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