Original Communication

Validation of a Quantitative Food Frequency Questionnaire for a Japanese Population in Hawaii

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Abstract: Objective: To measure the validity of a quantitative food frequency questionnaire (QFFQ). Design*:* A cross-sectional validation study of the QFFQ against a four-day food record (4DR) using Spearman correlation, cross-classification, kappa statistics, and Bland–Altman plotting. Setting*:* The Gastroenterology Department of Kaiser Permanente Hawaii. Subjects: 76 healthy Japanese American men and women, aged 40–75 years. Results*:* Somewhat stronger average correlations were observed between the QFFQ and the 4DR for macronutrients compared to micronutrients (Spearman *rho* of 0.47 vs. 0.35). Moderate correlations between the two tools were observed for macronutrients (including saturated fatty acids and dietary fibre), iron, β-carotene, vitamin C, and ethanol (*rho*: 0.38–0.58). Overall, stronger correlations were found among men than women between the two tools (mean *rho* 0.41 vs. 0.26). In a cross classification analysis, for more than 75% of the observations, a complete to relative agreement between the two methods was observed for fat, α-carotene, folate, vitamin D, and ethanol. Sex difference in agreement was minimal in cross-classification (overall extreme misclassification of 9.80% for men and 12.40% for women). Bland–Altman plots showed over-estimations of dietary fibre and α-carotene intake and an under-estimation of cholesterol intake by the QFFQ at high levels of consumption. However, the QFFQ estimation for fat, dietary fibre, folate, cholesterol, α-carotene, vitamins D and C, and ethanol intake was less than 7% different compared to the 4DR. Conclusions: The QFFQ has an adequate validity for fat, folate, vitamin D, and ethanol and can correctly categorize participants for intakes of cholesterol, dietary fibre, α-carotene, and zinc.

Keywords: Japanese Americans, food frequency questionnaire, validation

Introduction

Diet and nutrition have been recognized as some of the main modifiable risk factors for several types of cancers [1, 2], including colorectal cancer (CRC) - the third most common cancer worldwide. Exposure to a Western lifestyle, including a high consumption of red and processed meats, increases risk of CRC [1, 3, 4]. Increases in CRC incidence among Japanese immigrants to Hawaii and among residents of Japan in recent decades are often cited as examples of the effect of the Western lifestyle on CRC risk [5]. However, this large effect could be partly due to a specific susceptibility for CRC in Japanese populations [4].

With an age-standardized incidence rate of 59.8 to 53.6 per 100,000 population, Hawaii placed among the top ten states for CRC incidence rates in the United States between 2008 to 2010 [6]. In Hawaii, average colon cancer incidence rates among Japanese men were reported higher than among Caucasian men (34.4 vs. 32.7 per 100,000 population) [7] and other migrant groups [8]. Since 1987, cases of colorectal adenocarcinoma among five ethnic groups in Hawaii (Japanese, Caucasian, Filipino, Hawaiian, and Chinese) have been studied for the role of lifestyle risk factors in the development of CRC [9]. Collecting accurate dietary intake data is an important part of such research.

An accurate assessment of past dietary habits and nutrient intake is necessary for the assessment of the diet-cancer association. This requires the use of a valid and culturally appropriate dietary data collection tool, designed specifically for the population under study. A food frequency questionnaire (FFQ) is overall the most useful dietary assessment tool for large epidemiological studies examining food intake over an extended period of time [10].

Recently, a large multiethnic case-control study of colorectal adenoma (a common precursor for CRC) was conducted in Hawaii (Hawaii study) [11]. During the Hawaii study, quantitative FFQs were developed for five ethnic groups in Hawaii to assess associations between potential

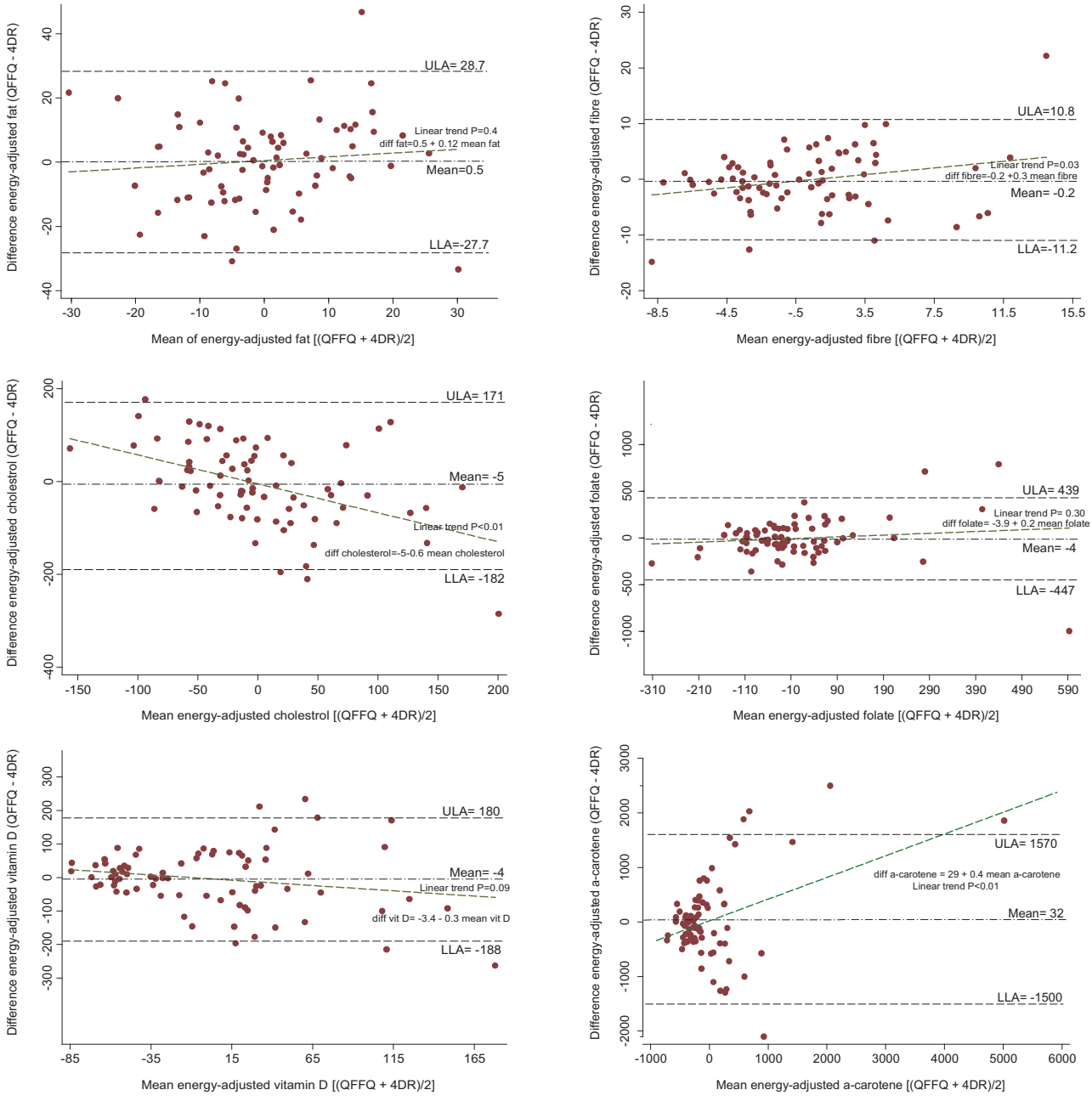

Figure 1. Bland–Altman plots for log transformed values (QFFQ: Quantitative food frequency questionnaire; 4DR: four-day food record; ULA: Upper limit of agreement; LLA: lower limit of agreement).

dietary risk factors and risk of colorectal adenoma. The aim of the present study was to further assess the validity of the QFFQ developed for a subset of Japanese participants in the Hawaii study using an approach that has been utilized in other publications [12–15].

Materials and Methods

In the multiethnic case-control Hawaii study, all subjects, aged 40–75 years, underwent a flexible sigmoidoscopy or colonoscopy at the Gastroenterology Department of Kaiser Permanente, Hawaii, to identify participants with (cases) or without (controls) colorectal adenoma [11]. Eighty Japanese controls in the Hawaii study [11] were successively re-contacted for this study. Subjects who reported a dietary regimen, or pregnant or breastfeeding women, were excluded from the re-contact.

The methods of developing the QFFQ in this study are similar to our previous study regarding Japanese populations living in Brazil and were described in detail previously [12]. Briefly, the participants first completed 3-day food

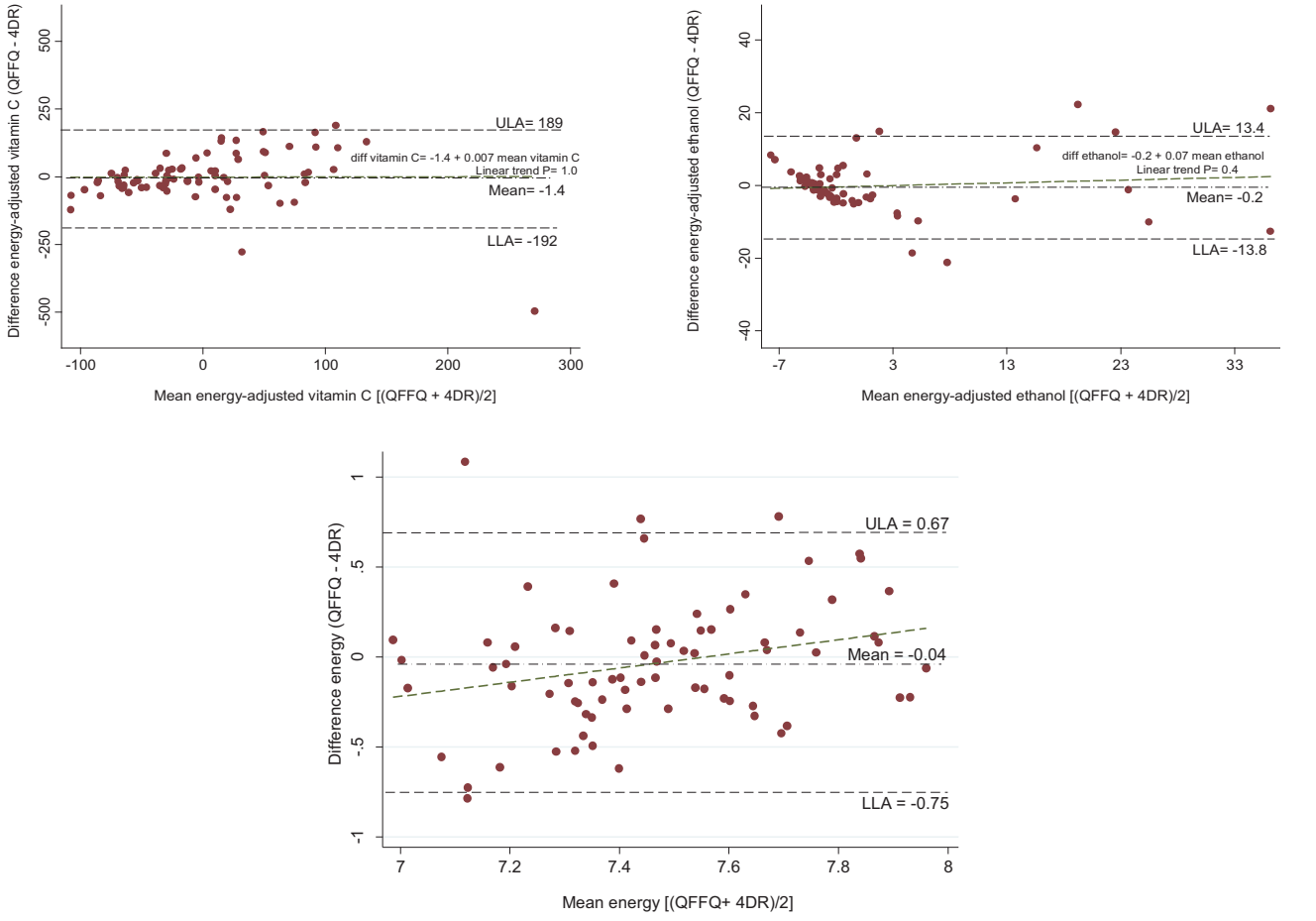

Figure 1. *(Continued)*

recalls. An ethnic-specific QFFQ was developed to reflect the dietary habits of Japanese participants living in Hawaii by using the food recall data of subjects who were cancer-free, non-pregnant, and non-breastfeeding. The QFFQ included 282 food items (Appendix 1), which provided at least 85% of the particular nutrient intake during a typical week or month [11]. The QFFQ was designed to measure dietary supplement intake, although this information was not included in this validation study [16]. The QFFQs were completed in the participants' homes between November 2001 and May 2007 as part of the Hawaii study. A trained interviewer completed the QFFQs with the participants, who were asked to estimate the overall frequency and amount of intake of each food item on the questionnaire over the preceding 12 months. To assist participants, three different portion sizes, measuring cups and spoons and colored photographs of various portion sizes, were used. In order to provide a reference for the QFFQ validation, four-day food records (4DR) were collected by the participants themselves between August 2006 and July 2007, throughout all four seasons of the year (median interval between QFFQ and 4DR: 9.6 months). A dietitian trained the participants in keeping a written record of all foods consumed throughout four consecutive 24-hour periods (had to include at least one Saturday or Sunday). Each participant received colored photographs of three different portion sizes (each of a small, medium, or large serving) for different food items. Participants were able to choose their own serving size based on the pictures. The dietitian was available via telephone to answer the participants' questions about completing the 4DR. The completeness of the food records was reviewed by the dietitian when they were returned to our Center.

Analysis

An estimate of individual j's daily intake of nutrient k (Y_{jk}), as given by 4DR in m weekdays and n weekend days, was calculated using the following formula: $Y_{jk=}[(\frac{5}{m}\sum_{d=0}^{m} Y_{jkd})+(\frac{2}{n}\sum_{d=0}^{n} Y_{jkd})] \div 7$. For the QFFQ, total daily intake of each food item (in grams) was computed by multiplying the daily frequency of intake by the selected portion size. The food composition database developed and maintained at the University of Hawaii Cancer Center [17] was used to extract

daily nutrient intake from the 4DR and QFFQ. The United States Department of Agriculture's nutrient database and other sources, including one from Japan [18], were used as sources for this food composition database.

Statistical methods

The validity of the QFFQ for accurate intake estimation of energy and 22 nutrients was assessed in this study. These nutrients are among the common potential predictors of colorectal adenoma, and comparable nutrients were chosen in other FFQ validation studies among Japanese populations [12, 19]. Statistical analysis methods similar to our previous publications [12–15] were used for this study. The mean and standard deviation (SD) of daily intake for each nutrient of interest were computed for the QFFQ and 4DR. Due to the lack of ability of the natural log transformation to normalize distributions adequately for a parametric test, a Wilcoxon signed-rank sum test was conducted to examine the null hypothesis of the equal nutrient intake measurements by the two dietary assessment tools. Strength of the relationship between the QFFQ and 4DR for nutrient intake estimation was measured by Spearman correlation coefficient (*rho*) due to the skewed distribution of the nutrient intakes. Due to the possibility of false-positive results (type I errors) by conducting multiple pairwise significance tests on the study data, *P*-values were considered statistically significant at $\alpha < 0.01$ for two-sided tests.

The energy-adjusted value for each nutrient was obtained by fitting a regression model to eliminate the effect of a positive correlation between energy and nutrient intake when there is a substantial variation in daily energy intake in our data [20]. *Rho* values were also corrected (de-attenuated) for within-person variance (i.e. day-to-day variation in diet) measured in the food records [21]. A de-attenuation index was computed for each nutrient using the formula: $[1 + ((\sigma_W^2/\sigma_B^2)/4]^{0.5}$ where σ_W^2 and σ_B^2 represent within-person and between-person variance, respectively [22].

Using the instrument-specific quartiles, cross-classification was conducted to evaluate the relative agreement between the two tools for distribution of nutrient intake. The percentage of observations in the same, adjacent, and opposite quartiles was respectively interpreted as complete agreement, relative agreement, and disagreement (gross misclassification) between the two tools. The weighted *k* was computed to provide a chance-corrected measure of cross-classification [23]. Kappa is the percentage of agreement, adjusted for chance, and the weighted *k* accounts for different levels of agreement in which the observed and expected proportions of agreement are modified to include partial agreement by assigning a weight between zero (complete disagreement) and one (complete agreement) to each category.

As Bland and Altman suggested, plotting the difference between two tools against their average shows mean agreement between the two methods at the individual level [24]. Upper and lower limits of agreement in the plots indicate the limits that 95% of differences are likely to fall within. These Bland–Altman plots were created for energy-adjusted values of nutrients in this study. To examine dependency between the two dietary assessment tools, a linear regression line of differences was fitted when the null hypothesis explains no dependency ($\beta = 0$) at $\alpha = 0.05$.

Stata MP, version 11 (Stata Corp LP, College Station, TX, USA) was used for all statistical analyses. The study was approved by the University of Hawaii Committee on Human Studies, and all participants signed a consent form.

Results

After excluding four observations (5%) with energy intakes of more than 20920 kJ (5000 kcal) per day from their QFFQ or 4DR, 35 Japanese men and 41 Japanese women with an average age of 63 (±10) years and 62 (±11) years, respectively, were included in the analyses. The mean years of education (including primary school, secondary school, and post-secondary levels) was 15 (± 3) years in both sex groups. In total, 228 weekdays and 76 weekend days were covered in the food records.

Mean daily intakes of energy and most nutrients were statistically similar between the QFFQ and the 4DR. However, the mean intakes of dietary fibre, vitamin A, α-carotene, β-carotene, folate, and vitamin C were higher and mean cholesterol intake was lower for the QFFQ compared to the 4DR ($P < 0.01$) (Table 1).

Before adjusting for energy, the mean value of crude and de-attenuated *rho* for energy and all 22 assessed nutrients were 0.32 (ranged 0.10–0.53) and 0.34 (ranged 0.10–0.55), respectively. Energy adjustment generally improved crude *rho* for most of the nutrients, except monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), cholesterol, zinc, vitamin B6, α-tocopherol, and ethanol (mean *rho* = 0.36, ranged 0.20–0.56). Mean de-attenuated energy-adjusted *rho* was stronger for macronutrients than micronutrients (0.47, ranged 0.41–0.50 and 0.35, ranged 0.21–0.58, respectively). The weakest correlation was observed for α-carotene (de-attenuated energy-adjusted *rho* = 0.21, $P = 0.08$) and the strongest for vitamin C (de-attenuated energy-adjusted *rho* = 0.58, $P < 0.01$). Moderate correlations [25] between the two tools were observed for macronutrients, saturated fatty acids (SFA), dietary fibre, iron, β-carotene, vitamin B6, vitamin C, and ethanol (ranged 0.38–0.58).

After adjusting nutrient intakes for energy and the participants' age, the mean de-attenuated *rho* was 0.41 (ranged

Table 1. Mean daily nutrient intake estimated by the QFFQ and 4DR, and Spearman correlation coefficients (*rho*) between the two questionnaires (crude, de-attenuated, energy and age adjusted *r* for all participants as well as men and women)

	QFFQ			4DR			Spearman correlation coefficient (rho)				
Nutrients	Median	Mean	SD	Median	Mean	SD	A	B	C	D	E
Energy (kJ)	7276	7590	2569	7485	7682	1908	0.33	–	–	–	–
Protein (g)	63.03	69.70	26.91	70.44	75.52	24.11	0.31	0.40	0.41	0.44	0.46
Fat (g)	61.02	70.18	31.29	71.78	74.17	25.03	0.47	0.48	0.50	0.40	0.47
SFA (g)	17.31	19.32	9.10	20.51	20.92	7.65	0.42	0.44	0.45	0.58	0.30
MUFA (g)	22.27	25.75	12.40	27.20	28.03	10.68	0.34	0.32	0.33	0.30	0.36
PUFA (g)	15.60	17.69	8.76	16.54	17.42	7.13	0.46	0.28	0.30	0.37	0.25
Cholesterol (mg)	175.28	206.26*	101.56	240.66	259.73*	123.80	0.33	0.33	0.35	0.58	0.10
Carbohydrate (g)	227.60	228.87	77.11	218.21	216.26	56.07	0.32	0.48	0.50	0.55	0.20
Dietary fibre (g)	17.39	18.62*	8.03	15.24	15.99*	5.26	0.28	0.52	0.54	0.23	0.53
Calcium (mg)	527.46	591.54	258.02	452.09	529.65	222.62	0.10	0.23	0.24	0.27	0.03
Iron (mg)	12.57	13.87	6.47	11.22	12.41	4.84	0.36	0.46	0.48	0.40	0.46
Zinc (mg)	9.90	10.77	5.26	9.26	9.97	3.55	0.30	0.24	0.25	0.17	0.30
Vitamin A (RAE) (μg)	581.87	661.22*	368.89	379.83	443.67*	245.20	0.21	0.26	0.27	0.20	0.05
α-carotene (μg)	643.87	953.35*	1010.18	271.90	485.27*	681.40	0.15	0.20	0.21	0.55	−0.16
β-carotene (μg)	3773.53	4617.17*	3458.54	1721.58	2502.64*	2308.90	0.35	0.40	0.41	0.39	0.02
Riboflavin (mg)	1.56	1.74	0.71	1.48	1.61	0.53	0.25	0.30	0.31	0.47	0.15
Vitamin B6 (mg)	1.76	1.88	0.88	1.50	1.67	0.81	0.53	0.50	0.52	0.39	0.42
Vitamin B12 (μg)	3.94	4.47	2.58	3.18	4.33	4.15	0.25	0.33	0.35	0.37	0.42
Folate (DFE) (μg)	429.52	485.22*	239.77	361.86	394.03*	182.71	0.13	0.26	0.27	0.41	0.11
Vitamin C (mg)	125.64	141.82*	87.05	73.55	97.49*	80.84	0.42	0.56	0.58*	0.50	0.22
Vitamin D (IU)	74.72	97.30	68.00	78.56	107.78	84.58	0.31	0.32	0.34	0.43	0.12
α-tocopherol (mg)	7.09	8.21	4.67	6.83	7.42	2.93	0.43	0.31	0.32	0.45	0.23
Ethanol (g)	0.13	4.47	9.95	0.10	4.58	9.90	0.42	0.37	0.38	0.65	0.69

A: crude *rho* unadjusted for energy, B: crude *rho* adjusted for energy, C: de-attenuated energy-adjusted *rho*, D: de-attenuated age and energy-adjusted *rho* for men, E: de-attenuated age and energy-adjusted *rho* for women; QFFQ: quantitative food frequency questionnaire; 4DR: four-day food record; SFA, Saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, Polyunsaturated fatty acids; RAE, Retinol activity equivalents; DFE, Dietary folate equivalents. *$P < 0.01$ for difference between mean intake estimated by QFFQ and 4DR.

0.17–0.65) for men and 0.26 (ranged 0.02–0.69) for women. Among men, a moderate correlation was observed between the two tools for all nutrients except MUFA, dietary fibre, calcium, zinc, and vitamin A. For women, however, the QFFQ was weakly correlated to the 4DR for the majority of nutrients except ethanol, fibre, protein, fat, MUFA, iron, and vitamins B6 and B12.

The cross-classification analysis showed that on average, one third (32.54%) of observations placed in the same quartiles versus 6.36% that were in opposite quartiles for estimation of energy and nutrient intake by the QFFQ and the 4DR (Table 2). In addition, more than 75% of observations from the QFFQ revealed a complete/relative agreement with the 4DR (weighted *k* ranged 0.29–0.58) for energy and 12 nutrients (total fat, SFA, MUFA, PUFA, carbohydrates, iron, β-carotene, α-tocopherol, vitamins B6, C, and D, and ethanol). The tools had the highest degree of disagreement for the estimation of calcium, α-carotene, and folate (weighted *k* ranged 0.08–0.12). After adjusting for energy, an overall 67.29% complete/relative agreement and 8.56% extreme misclassification between the two tools were found. The QFFQ showed zero percent misclassification for fat, cholesterol, dietary fibre, zinc, α-carotene, folate, and ethanol. More than 75% of observations placed in the same or adjacent quartiles for fat, α-carotene, folate, vitamin D and ethanol (weighted *k* ranged 0.32–0.60).

In the sex-specific cross-classification analysis of energy and age-adjusted nutrient values, on average, 66.36% (ranged 0–71.40%) and 9.80% (ranged 0–25.00%) of observations among men and 68.17% (ranged 0–80.00%) and 12.40% (ranged 0–42.90%) of observations among women placed in the same/adjacent and opposite quartiles, respectively (Table 3). In men, at least 75% of observations by the QFFQ were in complete or relative agreement with the 4DR for estimation of total fat, PUFA, carbohydrates, dietary fibre, zinc, folate, vitamin D, α-tocopherol, and ethanol. A similar relationship between the two tools was found for protein, MUFA, α-carotene, β-carotene, folate, vitamin D, and ethanol among women.

Considering the results of the cross-classification analysis, eight nutrients (fat, dietary fibre, folate, cholesterol, α-carotene, vitamin C, vitamin D, and ethanol) were tested using the Bland–Altman method (Figure 1). A wide scatter of differences was observed at higher levels of intake for

Table 2. Cross-classification of nutrient distribution quartiles from the QFFQ and the 4DR and weighted kappa statistics

Nutrient	Crude estimation of nutrient intake				Energy and age adjusted nutrient intake			
	Same quartile %	Adjacent quartile %	Opposite quartile %	Weighted k for crude values	Same quartile %	Adjacent quartile %	Opposite quartile %	Weighted k for adjusted values
Energy	36.80	39.50	5.30	0.36	–	–	–	–
Protein	27.60	44.70	2.60	0.33	21.70	47.80	4.30	0.23
Fat	35.50	46.10	1.30	0.49	36.00	48.00	0.00	0.55
SFA	34.20	40.80	3.90	0.36	33.00	41.70	12.50	0.29
MUFA	27.60	48.70	6.60	0.29	36.00	24.00	12.00	0.04
PUFA	34.20	43.40	3.90	0.39	39.10	30.40	8.70	0.30
Cholesterol	36.80	35.50	6.60	0.28	28.60	33.30	0.00	0.25
Carbohydrate	43.40	31.60	7.90	0.32	28.60	42.90	9.50	0.12
Dietary fibre	31.60	39.50	7.90	0.22	47.10	23.50	0.00	0.41
Calcium	21.10	51.30	11.80	0.12	14.30	35.70	21.40	−0.34
Iron	30.30	44.70	5.30	0.32	27.80	44.40	5.60	0.15
Zinc	25.00	43.40	3.90	0.24	28.60	42.90	0.00	0.39
Vitamin A (RAE)	22.40	48.70	9.20	0.16	28.50	23.20	23.10	−0.18
α-carotene	28.90	38.20	11.80	0.08	27.30	54.50	0.00	0.45
β-carotene	43.40	32.90	9.20	0.31	33.30	38.90	11.10	0.21
Riboflavin	26.30	44.70	7.90	0.20	15.80	26.30	21.10	−0.38
Vitamin B6	35.50	48.70	2.60	0.49	20.00	45.00	10.00	0.06
Vitamin B12	28.90	43.40	9.20	0.20	17.60	35.30	11.80	−0.17
Folate (DFE)	34.20	32.90	11.80	0.11	30.80	46.20	0.00	0.36
Vitamin C	35.50	42.10	5.30	0.37	22.20	38.90	11.10	−0.22
Vitamin D	30.30	46.10	6.60	0.31	33.70	42.90	14.30	0.32
α-tocopherol	34.20	44.70	2.60	0.43	35.30	23.50	11.80	0.13
Ethanol	44.80	43.30	3.00	0.58	50.00	35.70	0.00	0.60

QFFQ: quantitative food frequency questionnaire; 4DR: four-day food record; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; RAE: Retinol activity equivalents; DFE: Dietary folate equivalents.

nutrients included in the Bland–Altman plots. This pattern generally represented an over-estimation of total fat, dietary fibre, folate, α-carotene, and ethanol intake and under-estimation of cholesterol and vitamin D intake by the QFFQ at higher levels of consumption. However, the width of the limits of agreement in those plots represented narrow discrepancies between the two tools. In 95% of cases, the QFFQ estimated fat intake from 27.7 g less to 28.7 g more (mean 0.5 g) than the 4DR. This range was −11.2 g to 10.8 g (mean −0.2 g) for dietary fibre, −182 mg to 171 g (mean −5 mg) for cholesterol, −447 μg to 439 μg (mean −4 μg) for folate, −188 IU to 180 IU (mean −4 IU) for vitamin D, −1500 μg to 1570 μg (mean 32 μg) for α-carotene, −192 mg to 189 mg (mean −1.4 mg) for vitamin C, and −13.8 g to 13.4 g (mean −0.2 g) for ethanol.

Discussion

It was important to ensure the capacity and accuracy of the QFFQ to measure daily intake of nutrients of interest among Japanese Americans included in the Hawaii colorectal adenoma case-control study. In an FFQ validation study, the participants should be a subset of healthy people from the target population, as developing a validation study on a group of patients whose diet may be affected by the disease status or disease treatment will cause bias in the results. Therefore, we used a validated QFFQ to measure the dietary intake prior to disease development. The study aimed to assess the QFFQ accuracy and validity for nutrient intake measurement among healthy people (in the target population) who may or may not develop the disease. To check the validity of a QFFQ, the nutrient intake estimation by the QFFQ should be compared with relevant biomarkers and/or with a concurrent estimation from a reference tool. The fundamental issue in a validation study is that sources of error for the reference tool should be independent from the QFFQ; this is not completely feasible. As a result, biomarkers are thought to be the best reference tools for a QFFQ validation study. However, few valid recovery biomarkers exist as their levels are influenced by digestion, absorption, metabolism, and excretion in the body. In addition, biomarker measurements are often expensive and invasive. A food record, as used in this study, is a feasible and relatively accurate method of data collection, and

Table 3. Sex-specific cross-classification of nutrient distribution quartiles from the QFFQ and the 4DR. All calculations are based on energy and age-adjusted nutrient values.

Nutrient	Men			Women		
	Same quartile %	Adjacent quartile %	Opposite quartile %	Same quartile %	Adjacent quartile %	Opposite quartile %
Protein	18.10	54.50	9.00	21.40	57.10	21.40
Fat	23.10	61.50	0.00	21.40	50.00	0.00
SFA	38.50	30.80	23.10	10.00	40.00	0.00
MUFA	42.90	28.60	14.30	33.30	50.00	0.00
PUFA	25.00	50.00	12.50	27.30	36.40	18.20
Cholesterol	30.00	30.00	20.00	10.00	50.00	0.00
Carbohydrate	36.40	45.50	18.20	25.00	37.50	0.00
Dietary fibre	66.70	16.70	0.00	20.00	50.00	0.00
Calcium	25.00	37.50	12.50	11.10	22.20	33.30
Iron	28.60	42.90	0.00	18.20	45.50	0.00
Zinc	40.00	40.00	0.00	50.00	25.00	0.00
Vitamin A (RAE)	71.40	0.00	14.30	14.30	42.90	42.90
α-carotene	25.00	25.00	12.50	75.00	0.00	25.00
β-carotene	25.00	25.00	25.00	50.00	25.00	25.00
Riboflavin	12.50	37.50	0.00	0.00	66.70	33.30
Vitamin B6	28.60	0.00	0.00	33.30	33.30	0.00
Vitamin B12	20.00	20.00	10.00	40.00	30.00	10.00
Folate (DFE)	28.60	57.10	0.00	12.50	62.50	12.50
Vitamin C	14.30	14.30	14.30	22.20	44.40	22.20
Vitamin D	30.00	50.00	10.00	0.00	80.00	20.00
α-tocopherol	50.00	30.00	20.00	36.40	36.40	9.10
Ethanol	50.00	33.30	0.00	66.70	16.70	0.00

QFFQ: quantitative food frequency questionnaire; 4DR: four-day food record; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; RAE: Retinol activity equivalents; DFE: Dietary folate equivalents.

less likely to be influenced by common errors related to an FFQ (i.e. recall bias and poor inference of portion sizes) [26].

A simple technique for checking the QFFQ validity is to compare the mean nutrient intakes estimated by the QFFQ and a reference tool. In this study, the average estimations of dietary fibre, vitamin A, α-carotene, β-carotene, folate, and vitamin C intake were statistically significantly higher when estimated by the QFFQ compared to the 4DR. This finding could be related to an over-reporting of fruit and vegetable consumption by the QFFQ and indicates that the QFFQ had an overall relatively good agreement with the 4DR for estimation of energy and other nutrients. Comparison between means, however, is not sufficient to discriminate the FFQ validity at the individual level [27].

Spearman correlation is a common and relatively easy way to compare methods in many QFFQ validation studies. However, a correlation coefficient simply shows the strength of a relationship between the two tools, but not agreement, for measurement of a specific nutrient [28]. Energy and age-adjusted values of nutrients were used for the measurement of correlations in each sex independently, because energy intake, sex, and age can confound diet-disease association [20, 26]. The QFFQ moderately correlated with the 4DR for 77% of nutrients among men and 36% of nutrients in women. In addition, the mean de-attenuated *rho* was greater for men than women (0.41 and 0.26, respectively). This pattern was different from what has been observed in another study in a Japanese population [12]. As reported by Subar et al. [29], not providing sex-specific portion sizes in the QFFQ may create errors in absolute nutrient estimates and cause a substantial difference in mean de-attenuated *rho* between sexes. Regardless of the difference between sexes for the observed correlations, the QFFQ showed more concordance with the 4DR for estimation of ethanol, protein, total fat, iron, and vitamins B6 and B12 intakes in both sexes.

Using four categories (quartiles) instead of three categories as were used in some studies [30, 31], allowed us to provide a more detailed interpretation of the distribution pattern (i.e. complete and relative agreement) in the cross-classification analysis. In general and in sex-specific cross-classification analyses, a high proportion of people classified within the same or adjacent quartiles (75%), and the minimum levels of misclassification for fat, cholesterol, dietary fibre, folate, α-carotene, zinc, vitamin D, and

ethanol indicate the ability of the QFFQ to reasonably estimate intake for these nutrients.

The Bland–Altman plot method measures the agreement between the dietary assessment tools over the entire range of intakes (Figure 1). Plotting the difference against the mean of nutrient intake estimation by the two tools allowed us to identify any systematic differences between the tools [24]. The fitted regression lines showed that there were some systematic differences between the two tools for dietary fibre, cholesterol, and α-carotene intake measurements (linear trend $P < 0.05$). However, this was not the case for fat, folate, vitamin D, and ethanol. On average, the QFFQ energy intake estimation was 1.1% different from the 4DR, which is a substantially smaller difference compared to the correspondent index in other studies [32, 33] (6% to 27% difference). Further assessment on the eight plots, illustrated in this paper, indicated that the QFFQ was on average less than 7% different from the 4DR (ranged from 0.7% for fat to 6.6% for α-carotene) for the estimation of nutrient intakes. We observed that the QFFQ underestimated vitamin D intake, however, the estimate was not significantly different from the estimate assessed by the 4DR. We also observed a slight over-estimation of fat, dietary fibre, folate, α-carotene, and ethanol intake and an underestimation of cholesterol and vitamin D intake by the QFFQ at the higher levels of the consumption groups. This could be due to under-reporting of consumption of eggs and milk as the main sources of vitamin D in the study population. While there is not a consensus on the boundaries for interpretation of the difference between the test and reference tool [34], a 10% difference was considered to be an acceptable level of comparability between the QFFQ and 4DR in this study.

Sex differences in the validity of reported intake based on a QFFQ may obscure true sex differences in the relationships between diet and disease. Sex difference in the degree of correlation between the QFFQ and 4DR was quite pronounced in this study. However, the overall percentage of complete and relative agreement between the two tools was very similar (68% for women and 66% for men). The percentage of extreme misclassification was also 2.6% greater among women than men (12.4% for women and 9.8% for men). An FFQ validation against weighed food records [35] among Australian adults also reported a larger difference between the FFQ and the reference tools for nutrient intake estimation among women when compared to men.

A specific upper limit for daily energy intake was not defined in the literature. Considering the estimated daily energy need for a 100 kg man with a high intensity of physical activity (1.5–2 hours of vigorous physical activity 5–6 times per week) is 5280 kcal [12]; 5000 kcal per day was considered an extreme energy intake for this study.

All food and beverage items included in the QFFQ were sources of energy. Thus, the overall measurement error in the nutrient intake estimation was slightly reduced after adjusting the correlation coefficients for energy. A dramatic increase in correlation after adjusting for energy would indicate substantial portion size error; however, that was not an issue in this study.

A high degree of validity can be obtained when an FFQ includes 97 or more food items [36]. The Hawaii QFFQ was designed to include 282 Western and ethnic food items. The portion sizes were selected carefully from the food records that were collected to develop the QFFQ [16]; however, the QFFQ did not include sex-specific portion sizes, which may have improved data collection and analysis accuracy. Collecting food intake data over weekdays and weekends and throughout all four seasons increases the accuracy of the food record and accounts for any seasonal variability. However, the QFFQ may not have fully captured seasonal variety in food intake that presumably influenced the degree of agreement between two tools. A reference dietary assessment tool should cover the interval of time corresponding to the FFQ. Time differences between implementing an FFQ and the reference tool varied broadly from a few hours to 15 years in different validation studies [27]. A wider time difference might be associated with lower correlations between the two instruments. The median interval of 9.6 months between implementing the QFFQ and 4DR in this study, although in an acceptable range, might slightly reduce the correlation coefficients. The lack of a gold standard to assess long-term dietary intake is a limitation of all dietary validation studies. Biomarkers could be appropriate indices of true nutrient intake; however, they do not cover the total diet and are expensive [37]. A 24-hour recall, another common reference method in FFQ validation studies, is likely to overestimate the performance of the FFQ [26]. The 4DR was selected as the reference method since it more accurately reflects consumption, as recording is performed at the time of intake, while recall methods require the individual to recollect past dietary intake. This addresses an important requirement in validation studies that sources of error for the research and reference methods should be as independent as possible [26]. Finally, any possible errors in estimating alcohol would occur for all participants in both the case and control groups and would not impact the risk estimate in the main case-control study.

Conclusions

The Hawaii QFFQ has a reasonable validity to estimate total fat, folate, vitamin D, and ethanol. If the purpose of using the QFFQ is for ranking individuals rather than estimating the absolute intake, as would be in the Hawaii colorectal

adenoma case-control study, the QFFQ can also be considered a valid tool for the estimation of cholesterol, dietary fibre, α-carotene, and zinc.

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Conflict of interest
The authors declare that there are no conflicts of interest.

Author contributions
L.L.M. developed the conception and design of the study. S.S. contributed to the study design and oversaw data analyses. M.E. was responsible for overseeing all data collection as well as ensuring all protocols were adhered to. M.P., F.K., S.S., and L.L.M. assisted in the writing of the manuscript. M.P. also contributed to the data analyses and interpretations of results. All authors critically reviewed the manuscript.

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