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Dietary Patterns Associated with Functional Constipation among Japanese Women Aged 18 to 20 Years: A Cross-Sectional Study

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Summary Although several nutrients and foods have been suggested to be preventive for constipation, all previous studies have examined a single nutrient or food in each analysis. In contrast, analysis of dietary patterns may provide new insights into the influence of diet on functional constipation. We conducted a cross-sectional examination of the association between dietary pattern and functional constipation in 3,770 Japanese female dietetic course students aged 18–20 y from 53 institutions in Japan. Diet was assessed with a validated self-administered diet history questionnaire with 148 food items, from which 30 food groups were created and entered into a factor analysis. Functional constipation was defined using the Rome I criteria, which has previously been used in several epidemiologic studies on constipation. The prevalence of functional constipation was 26.0% (n=979). Four dietary patterns were identified: 1) "Healthy," 2) "Japanese traditional," 3) "Western," and 4) "Coffee and dairy products." After adjustment for several confounding factors, the "Japanese traditional" pattern, characterized by a high intake of rice, miso soup, and soy products and a low intake of bread and confectionaries, was associated with a significantly lower prevalence of functional constipation. In comparison with the lowest quintile, the multivariate adjusted odds ratio (95% confidence interval) was 0.52 (0.41–0.66) in the highest quintile (p for trend <0.0001). Other dietary patterns were not associated with functional constipation. The Japanese traditional dietary pattern, characterized by a high intake of rice and a low intake of bread and confectionaries, may be beneficial in preventing functional constipation in young Japanese women.
Key Words food-based dietary pattern, factor analysis, functional constipation, Japanese traditional dietary pattern, young Japanese women

Constipation is a common public health problem (*1*–*4*) with a well-recognized propensity to cause considerable discomfort and affect quality of life (*1*). Regarding nutritional approaches, although much attention has been focused on the benefit of dietary fiber (*5*–*10*), results to date have been inconsistent. Magnesium (*10*) and water from foods (*10*) have recently been postulated as preventive factors. For foods, various studies have observed associations between the prevalence of constipation and dairy products (*11*), beans (*11, 12*), meats (*11*), fruits (*11*), vegetables (*11*), rice (*3, 9, 12, 13*), eggs (*13*), confectionaries (*9, 12*), and some nonalcoholic beverages (*3, 5, 9, 11*). Nevertheless, the dominant approach of examining single nutrients or foods might not adequately account for complicated interactions and cumulative effects, which might in turn result in the drawing of erroneous associations between dietary factors and disease.

To overcome this limitation, the dietary pattern approach, or the measurement of overall diet, is now widely used to elucidate the relationship between diet and disease (*14, 15*). To our knowledge, however, no previous study has investigated the relationship between dietary pattern and prevalence of constipation. In addition, although the research standard or the definition of functional constipation includes various symptoms such as infrequency, straining, hard stools, and incomplete evacuation (Roma I criteria) (*16*), most previous studies have defined constipation according to the infrequency of bowel movement only (*5*–*8*) or the subjective perception of the patient (*9, 11*).

Here, we attempted to identify dietary patterns using factor analysis, and examined the relationships between dietary pattern and the prevalence of functional constipation as defined according to the Rome I criteria (*16*) among Japanese women aged 18 to 20 y.

SUBJECTS AND METHODS

Subjects and study design. The subjects were students newly enrolled in the dietetic course at 54 universities, colleges, and technical schools in Japan in April

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2005 (n=4,679). The study design, data-collection method, and study member list have been described in detail elsewhere (*10, 12*). In brief, two kinds of questionnaire on dietary habits and other lifestyle items during the preceding month were completed during an orientation session or first lecture given to freshman, in most institutions within 2 wk after the course began. A third questionnaire on lifestyle during the previous 6 y (i.e., junior and senior high school) was answered in similar fashion, in most institutions within 4 wk after the course began. A total of 4,286 students (4,066 women and 220 men) answered all three questionnaires (response rate=91.6%).

All questionnaires were checked at least once each by staff at the respective institution and at the survey center. Most surveys were completed by May 2005. The study protocol was approved by the Ethics Committee of the National Institute of Health and Nutrition.

Dietary assessment and food grouping. We used a self-administered diet history questionnaire (DHQ), a validated 16-page questionnaire which assesses dietary habits in the preceding 1-mo period (*17, 18*). A detailed description of the questionnaire, calculation of food and nutrient intakes, and validity is given elsewhere (*17, 18*). Measures of dietary intake for 148 food and beverage items and energy were calculated using an ad hoc computer algorithm for the DHQ, which was based on the Standard Tables of Food Composition in Japan (*19*). Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation of dietary intake.

To reduce the complexity of the data, food items were grouped together (*20*). The grouping scheme was generally based on the principles of similarity of nutrient profiles or culinary usage of the foods, mainly according to the Food Composition Tables of Japanese foods, 5th Revised Edition (*19*), and the classification of food groups used by the National Nutrition Survey (*21*). Finally, 30 separate food groups were established and used in analyses of dietary patterns (*20*).

Definition of constipation. A constipation questionnaire developed for a previous study (*2*) was incorporated into the 20-page questionnaire for lifestyle during the preceding 6 y. We used the definition of functional constipation recommended by an international workshop on the management of constipation (Rome I criteria) (*16*). Although the Rome I criteria were modified in 1999 (Rome II criteria) (*22*), epidemiologic studies have consistently shown that the latter may be too restrictive for the diagnosis of constipation (*2, 4*), and we therefore used the former. The following four questions were used to assess Rome I-defined functional constipation: 1) Do you strain during a bowel movement?; 2) Do you feel a sensation of incomplete emptying after a bowel movement?; 3) How often are your stools hard?; and 4) How many bowel movements do you usually have each week? These questions referred to the last 12 mo. For questions 1–3, four answers were offered: never, sometimes (<25% of the time), often (>25% of the time), and always. Functional constipation was defined as meeting two or more of the four criteria [an answer of often or always to questions 1–3 and less than three bowel movements per week for question 4].

Measurement of confounding factors. In the questionnaires, subjects reported body weight and height, residential area, current smoking (yes/no), and oral medication usage (yes/no). Body mass index (BMI) was calculated as body weight (kg) divided by the square of body height (m^2). Reported residential areas were grouped into six categories (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; and Kyushu) based on the regional blocks used in the National Nutrition Survey in Japan (*21*). Residential areas were also grouped into three categories according to population size (city with population ≥1 million; city with population <1 million; and town and village). Physical activity level was calculated by dividing total energy expenditure by basal metabolic rate calculated using the FAO/WHO/UNU formula (*23*). The calculation method has been described in detail elsewhere (*10, 12*).

Statistical analysis. For the current analysis, we selected female subjects aged 18–20 y (n=3,967). Of these, 197 women were excluded for the following reasons: attendance at an institution which conducted the survey at the end of May (n=97); reported daily energy intake outside the range of 3.7–4.7 MJ (725–3,235 kcal) (*24*) (n=78); or missing information on the variables used (n=24). Thus, 3,770 women underwent final analysis. Further exclusion of subjects with intentional dietary change during the preceding year (n=615) or those habitually using oral laxatives (n=367) did not materially alter the findings, and these subjects were therefore included in the analysis.

Factor analysis (principal component) was conducted to derive the food pattern based on the 30 food groups from the DHQ using the FACTOR PROCEDURE of the SAS software (*25*). Intake of these food groups was adjusted for total energy intake using the residual method (*26*). The factors were rotated by orthogonal transformation (Varimax rotation function in SAS) to achieve a simpler structure with greater interpretability. To identify the number of factors to be retained, we used the eigenvalue >1.0 criterion, the most widely used in factor analysis, as a first step. However, this procedure created 11 independent factors, a number too large for further analyses. The scree plot showed small breaks in the eigenvalues after factor five, suggesting that retaining three or four factors would be optimal. Post-rotated factor loadings revealed that four factors well described distinctive dietary patterns of the study population. After Varimax rotation, factor scores were saved from the principal component analysis for each individual. The factor scores for each pattern and for each individual were determined by summing the intake of each food group weighted by the factor loading (*27*).

The scores were divided into quintiles, and used for comparison with nutrient intake and other lifestyle factors and to estimate associations with the prevalence of

Table 1. Subject characteristics (n=3,770).[a]

Variable	
Age (y)	18.1±0.33
Body height (cm)	157.9±5.3
Body weight (kg)	52.3±7.6
Body mass index (kg/m²)	21.0±2.8
<18.5	550 (15)
18.5–24.9	2,937 (78)
≥25	283 (8)
Residential block	
Hokkaido and Tohoku	372 (10)
Kanto	1,290 (34)
Hokuriku and Tokai	526 (14)
Kinki	756 (20)
Chugoku and Shikoku	416 (11)
Kyushu	410 (11)
Size of residential area	
City with population ≥1 million	736 (20)
City with population <1 million	2,458 (65)
Town and village	576 (15)
Current smoking	
No	3,716 (99)
Yes	54 (1)
Oral medication usage	
No	3,403 (90)
Yes	367 (10)
Energy intake (MJ/d)	7.6±2.0
Physical activity level	1.40±0.17
Functional constipation[b]	
No	2,791 (74)
Yes	979 (26)

[a] Values are expressed as means±SD or numbers of subjects (%).
[b] Defined according to the Rome I criteria (*14*).

Table 2. Factor-loading matrix for the four dietary patterns (n=3,770).[a,b]

	Factor 1 Healthy	Factor 2 Japanese traditional	Factor 3 Western	Factor 4 Coffee and dairy products
Green and dark yellow vegetables	0.73	—	—	—
White vegetables	0.71	—	—	—
Mushrooms	0.62	—	—	—
Seaweeds	0.55	—	—	—
Soy products	0.50	0.36	—	—
Fish and shellfish	0.49	—	—	—
Potatoes	0.49	—	—	—
Processed fish	0.44	—	—	—
Fruit	0.41	—	—	—
Salted vegetables	0.31	—	—	—
Tea	—	—	—	—
Nuts	—	—	—	—
Rice	—	0.77	—	—
Miso soup	—	0.47	—	—
Fruit and vegetable juices	—	—	—	—
Alcohol	—	—	—	—
Noodles	—	—	—	—
Breads	—	−0.60	—	—
Confectionaries	—	−0.70	−0.33	—
Fats and oils	—	—	0.60	—
Meats	—	—	0.58	—
Seasonings	—	—	0.51	—
Processed meats	—	—	0.46	—
Eggs	—	—	0.33	—
Butter	—	—	—	—
Sugary foods	—	—	—	0.70
Coffee	—	—	—	0.69
Dairy products	—	—	—	0.41
Soup	—	—	—	—
Soft drinks	—	—	—	—
Percentage of variance	10.8%	6.9%	6.1%	5.3%

[a] Data from the self-administered diet history questionnaire (DHQ).
[b] Absolute values <0.27 were excluded from the table for simplicity.

functional constipation. Correlation coefficients for each factor and energy-adjusted nutrient intake were calculated. In logistic regression analysis, we calculated both crude and multivariate-adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for functional constipation for each quintile category of dietary pattern using logistic regression analysis. Multivariate-adjusted ORs were calculated by adjusting for BMI (three categories), residential block (six categories), size of residential area (three categories), current smoking (two categories), oral medication usage (two categories), physical activity level (quintiles), and energy intake (quintiles). We tested for linear trends across categories of dietary patterns by assigning scores to the levels of the independent variables.

All statistical analyses were performed using version 8.2 of the SAS software package (SAS Institute, Inc., Cary, North Carolina, USA). A two-sided p value of <0.05 was considered significant, except in correlation analyses between dietary patterns and nutrient intakes because these were not necessarily independent of each other. A Pearson correlation coefficient of >0.2 or <-0.2 was considered significant.

RESULTS

Subject characteristics are shown in Table 1. A total of 979 women (26%) were classified with functional constipation.

The factor loading matrix is shown in Table 2. High positive loadings indicate strong associations between given food groups and patterns, whereas negative loadings indicate negative associations. Patterns were labeled according to those food groups with high loadings. Factor 1, which loaded heavily on green and white vegetables, mushrooms, seaweeds, soy products, fish and shellfish, potatoes, and fruit, was labeled the "Healthy" pattern. Factor 2, with high loadings for rice, miso soup and soy products was labeled the "Japanese traditional" pattern. Factor 3, with high loadings for fats and oils, meat, processed meat, eggs, and seasoning was labeled the "Western" pattern. Factor 4, with high loadings for sugary foods, coffee, and dairy products was labeled the "Coffee and dairy products" pattern. The four dietary patterns overall accounted for 29.1%

Table 3. Sample characteristics for the lowest (Q1) and highest (Q5) quintiles of four dietary patterns (n=3,770).[a,b]

	Factor 1 Healthy		Factor 2 Japanese traditional		Factor 3 Western		Factor 4 Coffee and dairy products	
	Q1 (n=754)	Q5 (n=754)	Q1 (n=754)	Q5 (n=754)	Q1 (n=754)	Q5 (n=754)	Q1 (n=754)	Q5 (n=754)
Age (y)[c]	18.1±0.3	18.1±0.3	18.1±0.4	18.1±0.4	18.1±0.3	18.1±0.3	18.1±0.3	18.1±0.4*
Body height (cm)	157.9±5.4	158.0±5.4	158.2±5.3	157.7±5.2	158.4±5.2	157.7±5.4	157.9±5.3	157.8±5.1
Body weight (kg)	52.8±7.9	52.1±7.5	52.1±7.4	52.8±7.8	52.0±7.3	52.6±7.9	52.5±7.8	52.1±7.2
Size of residential area								
City with population ≥1 million	144 (19)	162 (22)	176 (23)	145 (19)	152 (20)	161 (21)	148 (20)	174 (23)
City with population <1 million	484 (64)	465 (62)	497 (66)	475 (63)	496 (66)	476 (63)	487 (65)	470 (62)
Town and village	126 (17)	127 (17)	81 (11)	134 (18)	106 (14)	117 (16)	119 (16)	110 (15)
Current smoker	19 (3)	2 (0)	18 (2)	6 (1)	9 (1)	16 (2)	14 (2)	10 (1)
Oral medication usage	47 (6)	107 (14)	85 (11)	82 (11)	99 (13)	72 (10)	65 (9)	95 (13)
Energy intake (MJ/d)[c]	8.0±2.0	8.2±2.00	8.2±2.2	7.8±2.0**	8.1±2.1	8.3±2.1*	8.1±2.1	8.2±2.1
Physical activity level[c]	1.40±0.18	1.43±0.19**	1.42±0.19	1.41±0.17	1.42±0.20	1.41±0.18	1.41±0.19	1.40±0.15

[a] The factors were standardized continuous variables, and each subject had a score for each factor.
[b] Values are expressed as means±SD or numbers of subjects (%).
[c] Significantly different from the first quintile (Q1) of each dietary pattern, *$p<0.05$, **$p<0.001$ (Dunnett's t-test).

of variance in food intake.

The subjects were divided into quintiles by the factor score of each dietary pattern. Sample means and frequencies were calculated across quintiles. Sample characteristics of young women in the lowest and highest quintiles of each food pattern are presented in Table 3. Subjects with a high intake of the Healthy pattern were physically active, while those with a high intake of the Japanese traditional pattern had a high BMI, low energy intake, and were more likely to live in a small town. Subjects with a high intake of the Western pattern had a high BMI and high energy intake.

Correlation coefficients between each of the four dietary patterns and energy-adjusted nutrient intakes are presented in Table 4. For energy-adjusted nutrient intake, the Healthy pattern was correlated with protein, vitamin A, vitamin C, calcium, potassium, magnesium, soluble dietary fiber, insoluble dietary fiber, total dietary fiber, water from foods, water from fluid, and water from all foods (Pearson correlation coefficient $(r)=0.22$–0.82). The Japanese traditional pattern was positively correlated with carbohydrate, magnesium, and water from foods ($r=0.21$–0.37), and negatively with fat ($r=-0.34$). The Western pattern was positively correlated with fat and protein ($r=0.31$–0.64), and negatively with carbohydrate, and soluble and total dietary fibers ($r=-0.68$–-0.21). The Coffee and dairy products pattern was positively correlated with calcium, potassium, and magnesium ($r=0.27$–0.44).

Multivariate-adjusted odds ratios for functional constipation across quintiles of all four dietary patterns are presented in Table 5. There was a clear dose-response relationship between a high intake of the Japanese traditional pattern and a decreased prevalence of constipation. In comparison with the first quintile of the Japanese traditional pattern, multivariate-adjusted odds ratios for women in the second, third, fourth and fifth quintiles were 0.77 (95% CI: 0.62–0.96), 0.74 (95% CI: 0.59–0.92), 0.66 (95% CI: 0.52–0.83), and 0.52 (95% CI: 0.41–0.66), respectively (p for trend <0.0001). No association with prevalence of functional constipation was seen for the other dietary patterns.

DISCUSSION

To our knowledge, this is the first study on the association between dietary pattern and the prevalence of functional constipation. The Japanese traditional pattern showed a strongly negative correlation with the prevalence of functional constipation.

Although constipation is a common condition in several communities, a precise determination of prevalence is not always easy owing to inconsistency among symptoms (*2*, *28*, *29*). In the present study, we used the standard definition of functional constipation recommended by an international workshop on the management of constipation (Rome I criteria) (*16*) to assess functional constipation from various symptoms. The prevalence of functional constipation defined by the Roma I criteria in this population was 26%. A similar

Table 4. Pearson correlation coefficients between each of the four dietary patterns and daily nutrient intakes (n=3,770).[a,b]

	Factor 1 Healthy	Factor 2 Japanese traditional	Factor 3 Western	Factor 4 Coffee and dairy products
Protein (g/d)	0.56	0.12	0.31	0.09
Fat (g/d)	0.09	−0.34	0.64	0.15
Carbohydrate (g/d)	−0.19	0.23	−0.68	−0.12
Vitamin A (mg/d)	0.49	0.08	0.06	0.17
Vitamin C (mg/d)	0.68	−0.01	−0.01	0.07
Calcium (mg/d)	0.42	0.09	−0.16	0.44
Potassium (mg/d)	0.77	0.10	0.00	0.33
Magnesium (mg/d)	0.67	0.21	−0.08	0.27
Soluble dietary fiber (g/d)	0.71	−0.20	−0.20	0.19
Insoluble dietary fiber (g/d)	0.82	0.04	−0.20	0.18
Total dietary fiber (g/d)	0.82	−0.03	−0.21	0.18
Water from foods (g/d)	0.79	0.37	0.04	0.07
Water from fluid (g/d)	0.22	−0.02	0.01	0.08
Total water (g/d)	0.41	0.08	0.02	0.11
Alcohol (g/d)	−0.05	−0.08	0.02	−0.02

[a] All nutrients were energy-adjusted using the residual method.
[b] Pearson correlation coefficients of >0.2 or <−0.2 were considered significant.

Table 5. Multivariate adjusted odds ratios and 95% confidence intervals for functional constipation by quintile (n=754 for each quintile) of each dietary pattern (n=3,770).[a]

	Quintile category of dietary pattern					
	1 (lowest) (referent)	2	3	4	5 (highest)	*p* for trend
Factor 1 (Healthy)						
n with functional constipation	214	177	186	190	212	
Non-adjusted OR (95% CI)	1.00	0.77 (0.61–0.98)	0.83 (0.66–1.04)	0.85 (0.68–1.07)	0.99 (0.79–1.24)	0.81
Multivariable adjusted OR (95% CI)[b]	1.00	0.75 (0.59–0.95)	0.81 (0.64–1.02)	0.83 (0.66–1.05)	0.93 (0.74–1.17)	0.79
Factor 2 (Japanese traditional)						
n with functional constipation	246	203	197	180	153	
Non-adjusted OR (95% CI)	1.00	0.76 (0.61–0.95)	0.73 (0.59–0.91)	0.65 (0.52–0.81)	0.53 (0.42–0.66)	<0.0001
Multivariable adjusted OR (95% CI)[b]	1.00	0.77 (0.62–0.96)	0.74 (0.59–0.92)	0.66 (0.52–0.83)	0.52 (0.41–0.66)	<0.0001
Factor 3 (Western)						
n with functional constipation	206	183	198	183	209	
Non-adjusted OR (95% CI)	1.00	0.85 (0.68–1.07)	0.95 (0.75–1.19)	0.85 (0.68–1.07)	1.02 (0.81–1.28)	0.87
Multivariable adjusted OR (95% CI)[b]	1.00	0.87 (0.69–1.10)	0.98 (0.78–1.24)	0.90 (0.71–1.14)	1.06 (0.84–1.33)	0.59
Factor 4 (Coffee and dairy products)						
n with functional constipation	201	166	216	200	196	
Non-adjusted OR (95% CI)	1.00	0.77 (0.61–0.98)	1.11 (0.89–1.38)	0.99 (0.79–1.25)	0.97 (0.77–1.22)	0.53
Multivariable adjusted OR (95% CI)[b]	1.00	0.76 (0.60–0.97)	1.09 (0.87–1.37)	0.98 (0.78–1.24)	0.92 (0.73–1.16)	0.80

[a] Functional constipation was defined according to the Rome I criteria (*14*).
[b] Adjusted for body mass index (<18.5, 18.5–24.9, and ≥25 kg/m²), residential block (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; and Kyushu), size of residential area (city with population ≥1 million; city with population <1 million; and town and village), current smoking (yes or no), oral medication usage (yes or no), physical activity level (quintile), and energy intake (quintile).

prevalence according to these criteria has been observed in Canadian women, at 21% (*4*), and in Spanish women, at 29% (*2*). In contrast, the lower ratio of 15% was reported for elderly Singaporean women (*3*).

At the food level, beneficial effects on constipation have been reported for dairy products such as cheese and milk (*11*), beans (*11*, *12*), fruits and vegetables (*11*), meats (*11*), rice (*3*, *9*, *12*, *13*), eggs (*13*), coffee (*11*), Chinese tea (*3*, *9*), and Japanese tea (*9*), although the results have not always been consistent. Among these results, however, the favorable effect of rice on constipation has been consistently reported in those studies conducted in Asian countries, where rice is a staple food (*3*, *9*, *12*, *13*). In the previous studies, the prevalence of constipation significantly negatively and positively associated with the intakes of rice and confectionaries, respectively (*9, 12*). The highest loadings in the Japanese traditional pattern were given to rice and confectionaries, positively and negatively, respectively (Table 2). Therefore, the observed strong association between the Japanese traditional dietary pattern and prevalence of constipation is probably explained mainly by these two foods.

With regard to individual nutrients, a protective effect has been seen for a high intake of dietary fiber in some studies (*5, 6*), but not in others, including ours (*7–10*). In contrast, the Healthy pattern, which was highly and positively associated with soluble, insoluble, and total dietary fibers, was not correlated with the prevalence of constipation. Our previous study using the same database showed a weak but significant negative association between the intake of magnesium and water from food and the prevalence of constipation (*10*). The Japanese traditional dietary pattern showed a positive association with the intakes of magnesium and water from foods (Table 4). These variables may therefore at least partly contribute to the lower prevalence of constipation. However, these two nutrients were associated with the Healthy dietary pattern much more strongly than with the Japanese traditional dietary pattern (Table 4). It may indicate the existence of unidentified nutrients or bioactive substances related to the prevalence of constipation in the Japanese traditional dietary pattern.

Our study has several limitations. First, the subjects were not randomly sampled from the general Japanese population, but were rather selected female students aged 18–20 y who might be highly health-conscious. To minimize the possible bias induced by nutritional education, we finished the survey within 1 mo of entrance to the course. Second, our findings came from a cross-sectional study. Because we could not exclude the possibility that the subjects changed their dietary behavior or food choices because of their condition of constipation, it was not possible to evaluate the causal association between dietary pattern and constipation. Third, Rome I criteria do not completely differentiate constipation-predominant irritable bowel syndrome from functional constipation (*28*). This might make the results obscure. Fourth, dietary habits and constipation were evaluated in different time periods, namely in the previous month for the former and in the previous year for the latter. However, the results did not materially change when analysis was limited to subjects reporting a stable diet within the previous year (n=3,155). Fifth, the validity and reproducibility of the dietary pattern identified in this study are unknown. However, the four patterns may be representative of Japanese populations because the same patterns were identified in our previous study among premenopausal Japanese farmwomen aged 40 to 55 y (*20*).

In conclusion, dietary pattern was associated with the prevalence of functional constipation among Japanese women aged 18 to 20 y. The Japanese traditional dietary pattern, characterized by a high intake of rice, miso soup, and soy products and a low intake of breads and confectionaries, may contribute to the prevention of functional constipation. Confirmation requires further studies using various populations with different dietary patterns.

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ORIGINAL ARTICLE

Validation of self-reported energy intake by a self-administered diet history questionnaire using the doubly labeled water method in 140 Japanese adults

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Objective: To validate reported energy intake (rEI) with a self-administered diet history questionnaire (DHQ) against total energy expenditure (TEE) by the doubly labeled water (DLW) method.
Subjects: A total of 140 healthy Japanese adults (67 men and 73 women) aged 20–59 years living in four areas in Japan.
Methods: Energy intake was assessed twice with DHQ over a 1-month period before and after TEE measurement (rEI_{DHQ1} and rEI_{DHQ2}, respectively). TEE was measured by DLW during 2 weeks (TEE_{DLW}).
Results: Mean rEI_{DHQ1} was lower than those of TEE_{DLW} by 1.9 ± 2.4 MJ/day (16.4%, $P<0.001$) for men and 0.6 ± 1.9 MJ/day (6.0%, $P<0.01$) for women. In men and women together, 62 subjects (44%) were defined as underreporters (rEI_{DHQ1}/TEE_{DLW} <0.84), 58 (41%) as acceptable reporters (0.84–1.16) and 20 (14%) as over-reporters (>1.16). Pearson correlation coefficient was 0.34 for men and 0.22 for women. After adjustment for the dietary and non-dietary factors related to rEI_{DHQ1}/TEE_{DLW}, the correlation coefficient improved to 0.42 and 0.37, respectively.
Conclusion: The energy intake assessed with DHQ correlated low to modestly with TEE measured by DLW. In addition, DHQ underestimated energy intake at a group level. Caution is needed when energy intake was evaluated by DHQ at both individual and group levels.
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Keywords: doubly labeled water; energy intake; self-administered diet history questionnaire; validation; Japanese adults

Introduction

Dietary intake estimates from self-administered dietary assessment methods such as questionnaires are commonly used in large-scale nutritional epidemiologic studies. Dietary assessment questionnaires have been developed for assessing habitual dietary intake and for ranking subjects according to their dietary intake. However, they cannot entirely avoid reporting errors (Barrett-Connor, 1991), including not only random but also systematic errors (Black and Cole, 2001; Livingstone and Black, 2003), due to the fact that they are self-reported.

In validation studies, data from dietary assessment questionnaires have often been compared with data from reference methods such as weighed diet records or 24 h recall (Willett and Lenart, 1998). However, all these dietary assessment methods were based on self-reporting. Therefore, the errors of both the new and reference methods might be correlated each other. The doubly labeled water (DLW) method, which measures the total energy expenditure (TEE) of subjects in free-living situations, has made it possible to validate reported energy intake (rEI) with an external biomarker (Hill and Davies, 2001; Trabulsi and Schoeller, 2001). The error of the DLW method is independent of self-rEI error (Livingstone and Black, 2003). However,

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relatively few validation studies of food frequency questionnaires against the DLW method have appeared (Sawaya *et al.*, 1996; Andersen *et al.*, 2003; Subar *et al.*, 2003). Furthermore, no such studies have been reported in non-Western countries.

The purpose of the present study was to examine the validity of energy intake assessed with a self-administered diet history questionnaire (DHQ) (Sasaki *et al.*, 1998) in comparison with TEE, as measured by the DLW method in a Japanese population.

Subjects and methods

Study population

This study was conducted in four districts of Japan from May to August 2003. We invited 40 healthy subjects (20 men and 20 women) aged 20–59 years from each of the four areas to participate, and distributed five subjects equally in each sex and age class of 20–29, 30–39, 40–49 and 50–59 years. Details of study recruitment and enrollment were described previously (Ishikawa-Takata *et al.*, 2007). All subjects providing written informed consent were finally considered eligible for the study. The total number of participants was 157 (78 men and 79 women).

Procedures

The study protocol was approved by the Ethics Committee of the National Institute of Health and Nutrition in Japan. The participants completed three visits over the study period and all participants completed the study. After recruitment, the participants were mailed an introductory letter and two dietary questionnaires including a DHQ, four physical activity questionnaires, and a supplemental questionnaire on lifestyle variables, and asked to fill them out and mail them back before the first visit (visit 1).

At visit 1, the participants had their questionnaires reviewed, their body weight and height measured and provided a baseline urine sample. At visit 2, on the morning following visit 1, they received a dose of DLW after an overnight fast. At visit 3, 14 days after visit 2, the participants brought urine samples and had their body weight and height measured.

After visit 3, the participants were mailed two dietary questionnaires including the DHQ, four physical activity questionnaires, supplemental questionnaire on lifestyle variables and diary about lifestyle during the period of TEE measurement.

All the collected questionnaires were checked by trained dietitians in each local center and again then in the study center. When missing answers, errors or both were found, the subjects were requested to answer the questions again.

Dietary assessment methods

Self-administered DHQ. The DHQ is a validated 16-page structured questionnaire, which assesses dietary habits in the preceding 1-month period (Sasaki *et al.*, 1998, 2000). Details of the questionnaire, methods of calculating nutrients and validity are given elsewhere (Sasaki *et al.*, 1998, 2000). Briefly, the DHQ consists of seven sections; (1) general dietary behavior, (2) major cooking methods, (3) consumption frequency and amount of six alcoholic beverages, (4) consumption frequency and semiquantitative portion size of 121 selected food and nonalcoholic beverage items, (5) dietary supplements, (6) consumption frequency and amount of 19 staple foods (rice, bread, noodles and other wheat foods) and miso soup (fermented soybean paste soup), and (7) open-ended items for foods consumed regularly (=once/week), which are not listed in the question. The food and beverage items and portion sizes in the DHQ were derived primarily from the data in the National Nutrition Survey of Japan (Sasaki *et al.*, 1998) and several recipe books for Japanese dishes. Measures of energy and dietary intakes for food and beverage items and dietary supplements with energy (148 food items in total) were calculated using an ad hoc computer algorithm for the DHQ, which was based on the Standard Tables of Food Composition in Japan (Science and Technology Agency, 2000). Information on dietary supplements, such as tablet, powder and liquid, which contained few energy and on data from the open-ended questionnaire items were not used in the calculation of dietary intake.

Anthropometric measures

Anthropometric measures were obtained at visits 1 and 3 by a single-trained study member. Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, in subjects wearing light clothing and no shoes. body mass index (BMI) was calculated as body weight (kg) divided by the square of body height (m^2).

Measurement of TEE with the DLW method

At visit 2, after a baseline urine sample was obtained, a single dose of approximately 0.06 g/kg body weight of ^2H_2O (99.8 atom%, Cambridge Isotope Laboratories, MA, USA) and 0.14 g/kg body weight of $H_2^{18}O$ (10.0 atom%, Cambridge Isotope Laboratories, MA, USA) was orally given to each subject via a drinking straw. After the dose administration, the subjects refrained from eating and drinking over a 4-h equilibration period (4 h sampling) for measurement of total body water. The second voided urine in the morning of day 1 (the day after the DLW dose) and day 14 (at the same time as the voiding on day 1) were collected for measurement of the isotopic (^2H and ^{18}O) elimination rate.

The procedure for specimen analysis and for subsequent data analyses was described previously (Ishikawa-Takata *et al.*, 2007). Briefly, the isotopic analyses were conducted using the Isotope Ratio Mass Spectrometry (IRMS) *DELTA Plus* equipment (Thermo Electron Corporation, Bremen, Germany) and calibrated using Vienna Standard Mean Ocean Water (V-SMOW), 302B, and the Greenland Ice Sheet Precipitation (GISP) standard provided by the International Atomic Energy Agency. Each measurement of samples and the corresponding references was performed in duplicate. The average s.d. through the analyses were 0.5‰ for ^2H and 0.03‰ for ^{18}O.

TEE (kcal/day) calculation was performed using a modified Weir's formula Weir, 1949 based on rCO_2 (mol/day) and food quotient (FQ):

$$TEE = 3.9 \times (rCO_2/FQ) + 1.1 \times (rCO_2)$$

FQ was derived from the dietary assessment data (g/day) of DHQ using an equation of Black *et al.* (1986). The average value of all subjects (0.867) was used for all subjects to estimate TEE.

Assessment of other variables possibly related to the rEI

Lifestyle, behavioral and psychological variables possibly related to the rEI were obtained from the four-page questionnaire as follows: educational attainment, alcohol drinking, history of diet experiences, desire for body weight change, and difference between ideal and measured body weight.

A physical activity level was calculated as TEE divided by basal metabolic rate (BMR). BMR was estimated according to the 6th Recommended Dietary Allowances for Japanese Ministry of Health Welfare (1999).

Statistical analysis

We excluded 17 subjects who was non-Japanese ($n = 1$), who was obese ($n = 1$), who did not complete at least first or second DHQ ($n = 2$), who had left more than 40 items blank in the questions regarding frequency for 121 selected food and beverage items in DHQ ($n = 4$), who rEI outside the range of 3.0–16.0 MJ/day ($n = 2$), or who did not provide sufficient urine sample volume ($n = 7$). Thus, 140 subjects (67 men and 73 women) were included in the present analysis.

As we monitored the body weight change during the assessment period of rEI by second DHQ (rEI_{DHQ2}), we estimated EI (eEI) from TEE_{DLW} with a correction for change in body energy store during the survey period (Bathalon *et al.*, 2000):

$$eEI = TEE + (\Delta wt \times 0.03)$$

where TEE is measured as MJ/day, Δwt is measured as g/day between visits 1 and 3, and 0.03 MJ/day (7 kcal/day) is the energy cost of weight change (Saltzman and Roberts, 1995). The eEI was used for the validation of rEI_{DHQ2}. In contrast, this correction of change in body energy store was not considered for the validation of rEI_{DHQ1} because of the lack of the monitoring.

The results were expressed as the mean and s.d. Mean differences between sexes and among methods were tested by the non-paired *t*-test and paired *t*-test, respectively. The Pearson and Spearman correlation coefficient was used to examine correlations between the test and the reference methods. Furthermore, the study participants were classified into tertiles of energy intake according to the distribution of

Table 1 Characteristics of 140 Japanese men and women aged 20–59 years included in the analyses[a]

	Men (n = 67)	*Women (n = 73)*
Age (years)	39.4±11.1	38.5±10.4
Body height (cm)	169.3±6.3	157.9±6.1[e]
Body weight (kg)	67.3±9.7	53.9±7.3[e]
BMI (kg/m^2)[b]	23.3±2.9	21.6±2.7[e]
<18.5	5 (7)	10 (14)[i]
18.5–24.9	39 (58)	55 (75)
⩾25.0	23 (34)	8 (11)
Educational attainment		
High school or less	28 (42)	23 (32)[h]
Technical or professional school	5 (7)	28 (38)
University or more	34 (51)	22 (30)
History of diet experience[c]		
No	58 (87)	57 (78)
Yes	9 (13)	16 (22)
Desire for weight change		
Reduction	37 (55)	50 (68)
No change	20 (30)	20 (27)
Increase	10 (15)	3 (4)
Difference between ideal and measured body weight (kg)[d]	−4.2±6.7	−4.5±4.3
Frequency of alcohol intake (times/week)	2.6±2.7	1.0±1.9[e]
Physical activity level	1.70±0.21	1.69±0.27
Body weight change during survey (g/day)	−23±55[j]	−2±45[g]
TEE_{DLW} (MJ/day)	10.7±1.7	8.3±1.2[e]
eEI_{DLW} (MJ/day)	10.0±2.1	8.2±2.0[e]
rEI_{DHQ1} (MJ/day)	8.8±2.4	7.7±1.7[f]
rEI_{DHQ2} (MJ/day)	8.9±2.5	7.4±1.5[e]

Abbreviations: BMI, body mass index; DHQ, diet history questionnaire; DHQ1, first measurement of DHQ before dose of DLW; DHQ2, second measurement of DHQ 2 weeks after dose of DLW; DLW, doubly labeled water method; eEI, estimated energy intake = TEE_{DLW} + (body weight change during survey × 0.03); rEI_{DHQ}, reported energy intake assessed with self-administered DHQ; TEE_{DLW}, total energy expenditure measured by DLW.
[a]Mean ± s.d. or *n* (%).
[b]The categorization was based on the Japan Society for the Study of Obesity (Matsuzawa *et al.*, 2000).
[c]Dieting was defined as at least 2 kg intentional reduction of body weight within 1 month.
[d]Ideal body weight was evaluated by the following question: how many kilograms is your ideal body weight? Difference between ideal and measured body weight was calculated, as ideal body weight (kg)—measured body weight (kg), to evaluate the degree of desire for body weight change.
[e–g]Difference between sexes by non-paired *t*-test: [e]$P < 0.001$, [f]$P < 0.01$, [g]$P < 0.05$.
[h,i]Significant difference between sexes in all categories by χ^2 test: [h]$P < 0.001$, [i]$P < 0.01$
[j]Difference within sexes from 0 by paired *t*-test: $P < 0.01$.

the test and the reference methods, and the proportions of subjects classified into the same, adjacent or opposite tertiles were determined.

To evaluate the prevalence of under- or over-reporters, we calculated 95% confidence limits of rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW} as a cutoff value proposed by Livingstone and Black (2003). Then, subjects with rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW} smaller than 0.84 or larger than 1.16 were considered as under- or over-reporters, respectively.

A stepwise multiple regression analysis was performed to evaluate the influence of sociodemographic, lifestyle, behavioral and psychological factors on rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW}, simultaneously. The following potential factors were entered into the model as the independent variables: age, BMI, body height, residential area, educational attainment, physical activity level, frequency of alcohol drinking, desire for body weight change, difference between ideal and measured body weight, and history of diet experience.

To examine the reproducibility, we compared mean rEIs between first and second DHQs (DHQ1 and DHQ2, respectively). Furthermore, the Pearson correlation coefficients were used to compare the rEIs assessed with DHQ1 and DHQ2.

All statistical analyses were performed using version 8.2 of the SAS software package (SAS Institute Inc., Cary, NC, USA). The test was considered significant at a *P*-value of <0.05.

Results

Basic characteristics of the study subjects, the mean TEE_{DLW}, eEI, first and second measurements of rEI by the DHQ (rEI_{DHQ1} and rEI_{DHQ2}) are shown in Table 1. Men had the higher BMI than women (23.3 versus 21.6 kg/m^2, $P<0.001$). Twenty-three of 67 men and eight of 73 women were overweight (BMI $\geqslant 25$ kg/m^2). This table also shows body weight change during the TEE measurement, between visits 1 and 3. Mean body weight in men, although not in women, significantly changed by -23 ± 55 g/day ($P<0.01$ by paired *t*-test). Mean rEI_{DHQ1} was significantly lower than mean TEE_{DLW} by 1.9 ± 2.4 MJ/day (16.4%, $P<0.001$) for men and 0.6 ± 1.9 MJ/day (6.0%, $P<0.01$) for women. Mean rEI_{DHQ2} was also significantly lower than mean eEI_{DLW} by 1.1 ± 2.7 MJ/day (9.1%, $P<0.001$) for men and 0.8 ± 2.4 MJ/day (4.6%, $P<0.01$) for women.

Table 2 shows reporting accuracy of energy intake assessed with DHQ expressed as rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW}. The rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW} was 0.84 and 0.91 for men and 0.94 and 0.95 for women, respectively, resulting in a significantly lower rEI_{DHQ1}/TEE_{DLW} ratio for men than for women ($P<0.05$). There was a wide range in reporting accuracy of DHQ1; 31 and 51% were identified as acceptable, and 58 and 32% as under-, and 10 and 18% as over-reporters for men and women, respectively.

The rEI_{DHQ1} and TEE_{DLW} were significantly correlated only for men (Pearson correlation coefficient $=0.34$, Spearman correlation coefficient $=0.33$), but not for women (0.22 and 0.16, respectively). Forty-one, 45 and 14% of the subjects were cross-classified into the same, the adjacent and the opposite tertiles of the respective distributions of rEI_{DHQ1} and TEE_{DLW}, respectively (Figure 1a). The results of the correlation between rEI_{DHQ2} and eEI_{DLW} were similar (Figure 1b).

Table 3 shows the results of multiple regression analysis with rEI_{DHQ1}/TEE_{DLW} and rEI_{DHQ2}/eEI_{DLW}, as the dependent variables to examine the prediction of accuracy of reporting energy intake. For men, frequency of drinking alcohol, the difference between ideal and measured body weight, and history of diet experience correlated significantly and

Table 2 Reporting accuracy of energy intake determined by the self-administered diet history questionnaire[a]

	DHQ1			*DHQ2*		
	All (n = 140)	*Men (n = 67)*	*Women (n = 73)*	*All (n = 140)*	*Men (n = 67)*	*Women (n = 73)*
Reporting accuracy[b]	0.89±0.22	0.84±0.21	0.94±0.22[c]	0.93±0.30	0.91±0.26	0.95±0.33
Underreporters (*n* (%))	62 (44)	39 (58)	23 (32)[d]	64 (46)	30 (45)	34 (47)
Acceptable reporters (*n* (%))	58 (41)	21 (31)	37(51)	48 (34)	27 (40)	21 (29)
Overreporters (*n* (%))	20 (14)	7 (10)	13 (18)	28 (20)	10 (15)	18 (25)
Pearson's correlation coefficient	0.40[e]	0.34[f]	0.22	0.36[e]	0.35[f]	0.11
Spearman correlation coefficient	0.35[e]	0.33[f]	0.16	0.36[e]	0.41[e]	0.07

Abbreviations: DHQ1, first measurement of DHQ before dose of DLW; DHQ2, second measurement of DHQ 2 weeks after dose of DLW; DLW, doubly labeled water; eEI, estimated EI.
[a]Mean±s.d. or *n* (%).
[b]Reporting accuracy was assessed as the ratio of energy intake to total energy expenditure (rEI_{DHQ1}/TEE_{DLW}) and the ratio of energy intake to estimated energy intake (rEI_{DHQ2}/eEI_{DLW}), respectively. eEI was determined by using a correction for change in body energy during the measurement period, as TEE±(body weight change during survey × 0.03). Under-, acceptable, and over-reporters were defined as the ratio rEI_{DHQ}/TEE_{DLW} and rEI_{DHQ}/eEI_{DLW} <0.84, 0.84–1.16 and >1.16, respectively.
[c]Difference between sex by non-paired *t*-test: $P<0.01$.
[d]Significant difference between sexes in all categories by χ^2 test: $P<0.01$.
[e,f]Correlation coefficients between two methods: [e]$P<0.001$, [f]$P<0.01$.

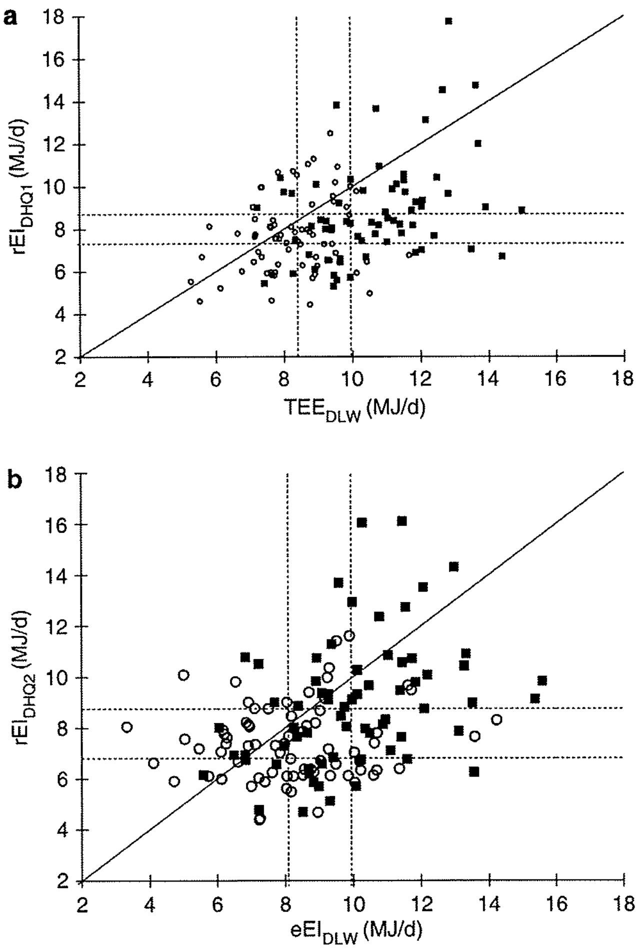

Figure 1 (**a**) Comparison of the first measurement of energy intake determined by the self-administered diet history questionnaire (rEI_{DHQ1}) with total energy expenditure measured by the doubly labeled water method (TEE_{DLW}) (■ = 67 men, ○ = 73 women). The dotted lines divide intake according to the tertiles of distribution. A straight line is $y = x$. Pearson and Spearman correlation coefficient was 0.40 and 0.35, respectively (both $P < 0.001$). (**b**) Comparison of the second measurement of energy intake determined by the self-administered diet history questionnaire (rEI_{DHQ2}) with estimated energy intake (eEI_{DLW}) determined by a correction of body weight change during survey period, as TEE + (Δwt × 0.03), (■ = 67 men, ○ = 73 women). The dotted lines divide intake according to the tertiles of distribution. A straight line is $y = x$. Pearson and Spearman correlation coefficient was both 0.36 ($P < 0.001$).

positively, and physical activity level negatively with rEI_{DHQ1}/TEE_{DLW}. For women, age and educational attainment correlated significantly and positively, and BMI negatively with rEI_{DHQ1}/TEE_{DLW}. We also conducted the same analysis with rEI_{DHQ2}/eEI_{DLW}. Body height, BMI and physical activity level significantly and negatively correlated with rEI_{DHQ2}/eEI_{DLW} for women. On the other hand, no factors attained the significance level for men.

The Pearson correlation coefficients between rEI_{DHQ1} and TEE_{DLW} slightly improved in both sexes after adjustment for the above-mentioned related factors (0.42 for men and 0.37 for women).

We also examined reproducibility of energy intake between DHQ1 and DHQ2. The rEI_{DHQ2} was significantly lower than rEI_{DHQ1} for women (the difference was -0.3 ± 1.1 MJ/day, $P = 0.03$), but not for men. The Pearson correlation coefficient between rEI_{DHQ1} and rEI_{DHQ2} was 0.79 for men and 0.76 for women.

Discussion

To our knowledge, this is the first report in a non-Western country to validate energy intake estimated with a dietary assessment questionnaire against TEE measured by DLW method. Moreover, the sample size was relatively large compared to the previous studies with the same purpose and method (Sawaya *et al.*, 1996; Kroke *et al.*, 1999; Andersen *et al.*, 2003).

The mean rEI_{DHQ1} was 11.0% less (16.4% for men and 6.0% for women) than the mean TEE_{DLW}. Several validation studies have shown that dietary assessment instruments underestimated daily energy intake (Livingstone *et al.*, 1990; Hill and Davis, 2001). The degree of such error, under- or overestimation, has also been examined using TEE measured by the DLW method (Sawaya *et al.*, 1996; Kroke *et al.*, 1999; Andersen *et al.*, 2003; Livingstone and Black, 2003). Average underreporting in the previous studies between EI from dietary assessment questionnaires and TEE measured by DLW ranged from 10 to 38% (Sawaya *et al.*, 1996; Subar *et al.*, 2003), which depends on sample size and subjects (Trabulsi and Schoeller, 2001).

For the individual ranking, the rEI_{DHQ1} significantly and positively correlated with TEE_{DLW} ($r = 0.40$, $P < 0.001$), showing a correlation similar to or relatively higher than those observed in the previous studies ($r = 0.06$–0.48) (Kroke *et al.*, 1999; Bathalon *et al.*, 2000). Acceptable reporting was observed in 41% of the subjects, whereas 44% underreported and 14% over-reported. Underreporting of energy intake therefore seems to be a more serious problem than over-reporting.

In this study, the mean rEI_{DHQ1}/TEE_{DLW} ratio was significantly lower in men than in women. Further, the rate of underreporting was higher in men than in women. In a previous analysis of individual data from 21 studies, in contrast, the proportion of underreporters did not statistically differ between sexes (Black, 2000). In our previous study using semi-weighed diet records in 4 days × 4 seasons, the mean value of the ratio of rEI to BMR estimated from sex, age and body weight was not statistically different between sexes (Okubo *et al.*, 2006). In the DHQ, the portion sizes of food items are standardized regardless of sex, for example as 'one small cup'. The subjects then select the relative portion size from the five categories given except for rice, bread, noodles, other wheat foods and miso soup. This structure

Table 3 Result of multiple regression analysis by stepwise procedure with the ratio of energy intake to total energy expenditure ($rEID_{HQ1}/TEE_{DLW}$ and rEI_{DHQ2}/eEI_{DLW}) as dependent variables[a]

Independent variable[b]	*Men (n = 67)*						*Women (n = 73)*					
	DHQ1			*DHQ2*			*DHQ1*			*DHQ2*		
	Partial regression coefficient[c]	*s.e.*[d]	*P-value*	*Partial regression coefficient*[c]	*s.e.*[d]	*P-value*	*Partial regression coefficient*[c]	*s.e.*[d]	*P-value*	*Partial regression coefficient*[c]	*s.e.*[d]	*P-value*
Age (years)	—	—	—	—	—	—	0.005	0.002	0.04	—	—	—
BMI (kg/m^2)	—	—	—	—	—	—	−0.036	0.009	<0.001	−0.049	0.015	<0.01
Body height (cm)	—	—	—	—	—	—	—	—	—	−0.016	0.006	0.02
Residential area	—	—	—	—	—	—	—	—	—	—	—	—
Educational attainment, (more than University versus high school or less as reference)	—	—	—	—	—	—	0.145	0.053	<0.01	—	—	—
Physical activity level	−0.356	0.120	<0.01	—	—	—	—	—	—	−0.480	0.154	<0.01
Frequency of drinking alcohol (times/week)	0.026	0.009	<0.01	—	—	—	—	—	—	—	—	—
Desire for body weight change	—	—	—	—	—	—	—	—	—	—	—	—
Difference between ideal and measured body weight (kg)	0.013	0.003	<0.01	—	—	—	—	—	—	—	—	—
History of diet experience (yes versus no as reference)	0.170	0.071	0.02	—	—	—	—	—	—	—	—	—

[a] TEE_{DLW}, total energy expenditure measured by doubly labeled water method (DLW); rEI_{DHQ}, reported energy intake assessed with self-administered diet history questionnaire (DHQ); DHQ1, first measurement of DHQ before dose of DLW; DHQ2, second measurement of DHQ 2 weeks after dose of DLW. Reporting accuracy were assessed as the ratio of energy intake to total energy expenditure (rEI_{DHQ1}/TEE_{DLW}) and the ratio of energy intake to estimated energy intake (rEI_{DHQ2}/eEI_{DLW}), respectively. Estimated EI (eEI) was determined by using a correction for change in body energy during the measurement period, as TEE + (body weight change during survey × 0.03).
[b] See table 1 for the definition of each independent variable. Age (as a continuous variable), BMI (as a continuous variable), body height (as a continuous variable), residential area (Hokuriku, Shikoku, North Kyushu, and South Kyushu), educational attainment (high school or less, technical or professional school, or university or more), physical activity level (as a continuous variable), frequency of alcohol drinking (as a continuous variable), desire for body weight change (reduction, no change or increase), difference between ideal and measured body weight (as a continuous variable), history of diet experience (yes or no).
[c] Partial regression coefficient; change in dependent variable related to a 1-U change in independent variable.
[d] Standard error (s.e.) of the regression coefficient.

might have led to relative over- and underreporting of energy in women and men, respectively.

The rEI_{DHQ1}/TEE_{DLW} was significantly and independently correlated with several anthropometric and behavioral factors (Table 3). Several previous studies have already examined non-dietary factors, such as physiological (Zhang *et al.*, 2000; Livingstone and Black, 2003) and psychological (Johansson *et al.*, 1998; Bathalon *et al.*, 2000; Tooze *et al.*, 2004) factors associated with reporting accuracy of energy intake. After adjusting for these variables, the validity slightly improved (Pearson correlation coefficient was 0.42 for men and 0.37 for women). Therefore, these non-dietary factors are needed to consider when evaluating rEI.

This study has several limitations. First, FQ was derived from dietary assessment data by DHQ. Therefore, TEE was not theoretically independent of EI. Second, the surveyed period for the first measurement of EI by DHQ (DHQ1) was ahead of, and not overlapping with, TEE measurement by the DLW method. Third, we used the TEE as gold standard for the validation of DHQ1 without any consideration for a possible body weight change during the assessment period because of lack of the data. Fourth, we used the TEE with a correction for change in body weight during the survey period as gold standard for the validation of DHQ2, because the body weight has significantly changed in men. Fifth, the change in body composition, such as change in fat mass and fat-free mass, is probably the better indicator than the change in body weight for the correction of energy content for the study purpose. Sixth, the rEI_{DHQ1} was significantly lower than the rEI_{DHQ2} for women. Intentional or non-intentional intervention effect might have influenced dietary behaviors between the first and the second measurement. As shown in Table 3, the factors affecting reporting accuracy of energy intake were different between the two measurements. This may be one of the reasons. Seventh, we applied a two-point rather than multipoint method for the measurement of TEE_{DLW}. Eighth, the subjects were not randomly sampled from the general Japanese population. Moreover, the survey areas were not equally distributed over the country but were rather selected mostly from the Western parts of Japan.

In summary, the energy intake assessed with DHQ correlated low to modestly with TEE measured by DLW. In addition, DHQ underestimated energy intake at a group level. Caution is needed when energy intake was evaluated by DHQ at both individual and group levels.

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Association between dietary acid–base load and cardiometabolic risk factors in young Japanese women

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Mild metabolic acidosis, which can be caused by diet, may adversely affect cardiometabolic risk factors, possibly by increasing cortisol production. Methodologies for estimating diet-induced acid–base load using dietary-intake information have been established. To our knowledge, however, the possible association between dietary acid–base load and cardiometabolic risk factors has not been investigated. We cross-sectionally examined associations between dietary acid–base load and cardiometabolic risk factors in a free-living population. The subjects were 1136 female Japanese dietetic students aged 18–22 years. Dietary acid–base load was characterized as the potential renal acid load (PRAL), which was determined using an algorithm including dietary protein, P, K, Ca and Mg, as well as the ratio of dietary protein to K (Pro:K). Estimates of each nutrient were obtained from a validated comprehensive self-administered diet history questionnaire. Body height and weight, waist circumference and blood pressure were measured. Fasting blood samples were collected. After adjustment for potential confounding factors, higher PRAL and Pro:K (more acidic dietary acid–base loads) were associated with higher systolic and diastolic blood pressure (*P* for trend=0·028 and 0·035 for PRAL and 0·012 and 0·009 for Pro:K, respectively). PRAL was also independently positively associated with total and LDL-cholesterol (*n* 1121; *P* for trend=0·042 and 0·021, respectively). Additionally, Pro:K showed an independent positive association with BMI and waist circumference (*P* for trend=0·024 and 0·012, respectively). In conclusion, more acidic dietary acid–base load was independently associated with adverse profile of several cardiometabolic risk factors in free-living young Japanese women.

Acid–base balance: Potential renal acid load: Ratio of dietary protein to potassium: Blood pressure

The potential importance of acid–base homeostasis to cardiometabolic risk factors has been recently suggested in the literature[1,2]. Mild metabolic acidosis, which can be caused by diet[3–5], may adversely affect blood pressure[6–8], possibly by increasing cortisol production[3], increasing Ca excretion[9,10] or decreasing citrate excretion[11]. Increased cortisol production caused by mild metabolic acidosis[3–5] may also have a detrimental influence on other cardiometabolic risk factors, including obesity and cholesterol[12–14].

Since acid–base status is markedly influenced by diet[15,16], diet-dependent acid–base load can be calculated based on dietary intake information. Remer and colleagues developed an equation for estimating potential renal acid load (PRAL), an indicator of dietary acid–base load, using the dietary intake of five nutrients (protein, P, K, Ca and Mg)[15,17]. In addition, Frassetto and colleagues proposed the ratio of dietary protein to K (Pro:K) as an indicator of dietary acid–base load[16]. Both PRAL and Pro:K estimated from dietary

Abbreviations: DHQ, diet history questionnaire; MET, metabolic equivalents; NAE, net acid excretion; OA, organic acids; PRAL, potential renal acid load; Pro:K, ratio of dietary protein to K.

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intake information have been validated against objective measures of acid–base load determined from 24 h urine (i.e. PRAL and net acid excretion (NAE), respectively)[17]. Using these measures, an expected negative relationship of dietary acid–base load with bone health was demonstrated in several epidemiologic studies that relied on a dietary questionnaire for nutrient intake estimation[18–22].

Despite the potential influence of dietary acid–base load on cardiometabolic risk factors and the availability of dietary acid–base load measurements using dietary intake data, no study has examined the possible association between measures of dietary acid–base load and cardiometabolic risk factors. Here, we investigated the associations of measures of dietary acid–base load (i.e. PRAL and Pro:K), calculated using nutrient intake estimates obtained from a validated self-administered comprehensive diet history questionnaire (DHQ)[23–25] with several cardiometabolic risk factors including BMI, waist circumference, systolic and diastolic blood pressure, total, HDL, and LDL cholesterol, fasting TAG, fasting glucose and glycated Hb, using data gathered from a cross-sectional observational study of free-living young Japanese women.

Subjects and methods

Subjects

The present study was based on a cross-sectional multi-centre survey conducted from February to March 2006 and from January to March 2007 among female dietetic students from fifteen institutions in Japan. All measurements at each institution were conducted according to the survey protocol. Briefly, staff at each institution explained an outline of the survey to potential subjects. Those who responded positively were then provided detailed written and oral explanations of the survey's general purpose and procedure. The protocol of the study was approved by the Ethics Committee of the National Institute of Health and Nutrition, and written informed consent was obtained from each subject, and also from a parent for subjects aged <20 years.

A total of 1176 Japanese women took part. For the present analysis, women aged 18–22 years were selected (*n* 1154), not only because dietetic students outside this age range are rare in Japan but also because their dietary and cardiometabolic characteristics may differ from those of dietetic students aged 18–22 years. We then excluded from the 1154 women aged 18–22 years those not completing survey questionnaires (*n* 1), those with extremely low or high reported energy intakes (<2092 or >16736 kJ/d; *n* 2), those currently receiving dietary counselling from a doctor or dietitian (*n* 13), those with previously diagnosed diabetes, hypertension or CVD (*n* 1), and those without measurement of body height and weight (*n* 2). Additionally, women with missing information regarding cardiometabolic risk factors were excluded from the respective analyses (*n* 2 for BMI, *n* 2 for waist circumference, *n* 0 for systolic and diastolic blood pressure, *n* 16 for cholesterol (total, HDL and LDL), *n* 16 for TAG, *n* 15 for glucose, and *n* 16 for glycated Hb). Further, those providing non-fasting blood samples (*n* 34) were excluded from the fasting TAG and glucose analyses. Some women fell into more than one exclusion category. The final sample size was 1136 for BMI, waist circumference, and systolic and diastolic blood pressure, 1121 for cholesterol (total, HDL, and LDL) and glycated Hb, 1089 for fasting glucose, and 1088 for fasting TAG.

Dietary assessment

Dietary habits during the preceding month were assessed using a self-administered comprehensive DHQ[23–25]. Responses to the DHQ, as well as to a lifestyle questionnaire, were checked at least twice for completeness. When necessary, forms were reviewed with the subject to ensure the clarity of answers. The DHQ is a sixteen-page structured questionnaire that consists of the following seven sections: general dietary behaviour; major cooking methods; consumption frequency and amount of six alcoholic beverages; consumption frequency and semi-quantitative portion size of 118 selected food and nonalcoholic beverage items; dietary supplements; consumption frequency and semi-quantitative portion size of nineteen cereals (rice, bread, and noodles), soup consumed with noodles, and *miso* (fermented soyabean paste) soup; and open-ended items for foods consumed regularly ($\geq$once/week), but not appearing in the DHQ[23]. The food and beverage items were selected as foods commonly consumed in Japan, mainly from a food list used in the National Nutrition Survey of Japan, and standard portion sizes were derived mainly from several recipe books for Japanese dishes[23].

Estimates of dietary intake for a total of 150 food and beverage items (including five seasonings), energy, and nutrients were calculated using an *ad hoc* computer algorithm for the DHQ based on the Standard Tables of Food Composition in Japan[26]. Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation of dietary intake[23]. Nutrient and food intake was energy-adjusted using the residual method[27]. Detailed descriptions of the methods used to calculate dietary intake and the validity of the DHQ regarding nutrients have been published elsewhere[23–25]. The Pearson correlation coefficients between the DHQ and the 3 d estimated dietary records for forty-seven women were 0·48 for protein, 0·59 for P, 0·68 for K, and 0·49 for Ca (data not available for Mg)[23]. The Pearson correlation coefficients between the DHQ and the 16 d weighed dietary records for ninety-two women were 0·52 for protein, 0·55 for P, 0·55 for K, 0·56 for Ca, and 0·56 for Mg (S. Sasaki, unpublished results). In addition, the Spearman correlation coefficients were 0·66 for meats, 0·55 for fish and shellfish, 0·38 for eggs, 0·61 for dairy products, and 0·40 for fruits, 0·57 for vegetables, and 0·46 for cereals in ninety-two women (S. Sasaki, unpublished results). Furthermore, the Pearson correlation coefficient between the DHQ and the 24 h urinary excretion for K was 0·40 in sixty-nine women[24].

Calculation and validation of dietary acid–base load measures

Urinary NAE is an established index of net endogenous acid production[16,17], which is difficult to measure directly[28,29]. Because the sum of cations excreted in the urine equals the sum of anions, urinary NAE is also equal to the difference between the sum of the major urinary non-bicarbonate anions minus the sum of the non-titratable acid and non-ammonium cations[30]. The amounts of these non-bicarbonate anions and mineral cations in urine (excluding organic acids (OA)) are primarily influenced by dietary nutrient intake[15,16]. OA are largely independent of dietary acid load or macronutrient composition[15,17,31,32], and can be reasonably estimated from body surface area[32]:

$$\text{OA (mEq/d)} = \text{body surface area (m}^2) \times 41/1{\cdot}73,$$

$$\text{where body surface area (m}^2) = 0{\cdot}0007484 \times \text{body height (cm)}^{0{\cdot}725} \times \text{body weight (kg)}^{0{\cdot}425}.$$

Thus, the estimate of the urinary difference in non-bicarbonate anions (without OA) and mineral cations can be considered an index of diet-induced acid load[17]. Remer and colleagues referred to this estimate as PRAL (i.e. NAE = PRAL + OA)[17], and developed the equation for estimating PRAL from dietary information[15,17,30]:

$$\text{PRAL (mEq/d)} = 0{\cdot}4888 \times \text{protein (g/d)} + 0{\cdot}0366 \times \text{P (mg/d)} - 0{\cdot}0205 \times \text{K (mg/d)} - 0{\cdot}0125 \times \text{Ca (mg/d)} - 0{\cdot}0263 \times \text{Mg (mg/d)}.$$

The validity of PRAL estimated from this equation has been established against PRAL measured from 24 h urine[15,17].

The rate of H_2SO_4 production from protein metabolism and the rate of bicarbonate generation from the metabolism of intestinally absorbed K salts are major and highly variable components of net endogenous acid production[29]. Based on this, Frassetto and colleagues proposed the ratio of dietary protein (g/d) to K (mEq/d) (i.e. Pro:K) as an index of diet-induced acid load[16]. The validity of Pro:K has been established against NAE measured in 24 h urine[17].

In the present study PRAL and Pro:K were used as measures of dietary acid–base load. PRAL and Pro:K were calculated according to the equations described above using crude nutrient intake data estimated from the DHQ. Higher values of PRAL and Pro:K mean more acidic dietary acid–base load. Calculated PRAL and Pro:K were then energy-adjusted using the residual method[27]. Prior to the present analysis, the relative validity of PRAL and Pro:K estimated from the DHQ was examined against that from the 16 d weighed dietary records in ninety-two women aged 31–69 years. The Pearson correlation coefficient between the two methods was 0·35 for PRAL and 0·37 for Pro:K (S. Sasaki, unpublished results).

Cardiometabolic risk factors

Cardiometabolic risk factors were measured 1–3 d after completion of the questionnaires. Body height was measured to the nearest 0·1 cm with the subject standing without shoes. Body weight in light indoor clothes was measured to the nearest 0·1 kg. BMI was calculated as body weight (kg) divided by the square of body height (m). Waist circumference was measured at the level of the umbilicus to the nearest 0·1 cm. The measurement was taken at the end of a normal expiration while the subject was standing erect with her arms at her side and feet together. Systolic and diastolic blood pressure was measured on the left arm with an automatic device (Omron model HEM-770A; Omron Health Care, Kyoto, Japan) after the subject had been sitting quietly for ≥3 min. A second measurement was carried out about 1 min after the first, and the mean value of the two was used. Peripheral blood samples were obtained from subjects after an overnight fast. Blood was collected in evacuated tubes containing no additives, allowed to clot, and centrifuged at 3000 *g* for 10 min at room temperature to separate the serum. Blood samples for glycated Hb measurements were also collected in evacuated tubes containing no additives. In accordance with the survey protocol, blood samples were transported at −20°C by car or airplane to ensure delivery to a laboratory in Tokyo, Japan (SRL, Inc. in the 2006 survey and Mitsubishi Kagaku Bio-Clinical Laboratories (MBCL), Inc. in the 2007 survey). Biochemical variables were assayed at SRL in the 2006 survey and MBCL in the 2007 survey within 1–2 d of collection to avoid significant degradation, as follows. Serum total cholesterol concentration was measured enzymically using a kit from Wako Junyaku Co. Ltd (Tokyo, Japan) at SRL and using a kit from Daiya Shiyaku Co. Ltd (Tokyo, Japan) at MBCL. Serum LDL- and HDL-cholesterol concentrations were measured enzymically using a kit from Daiichi Kagaku Co. Ltd at SRL and using a kit from Daiichi Kagaku Co. Ltd at MBCL. Serum TAG concentration was measured enzymically using a kit from Daiichi Kagaku Co. Ltd at SRL and using a kit from Kyowa Medex Co. Ltd (Tokyo, Japan) at MBCL. Serum glucose concentration was measured enzymically using a kit from Shino Tesuto Co. Ltd (Tokyo, Japan) at SRL and using a kit from Kanto Kagaku Co. Ltd (Tokyo, Japan) at MBCL. Glycated Hb was measured using whole blood by latex agglutination-turbidimetric immunoassay (Fuji Revio Co. Ltd (Tokyo, Japan) at SRL and Kyowa Medex Co. Ltd (Tokyo, Japan) at MBCL). In-house quality-control procedures for all assays were conducted at SRL in the 2006 survey and MBCL in the 2007 survey.

Other variables

In the lifestyle questionnaire, the subject reported her residential area, which was grouped into one of three regions (residential block: north (Kanto, Hokkaido, and Tohoku); central (Tokai, Hokuriku, and Kinki) or south (Kyushu and Chugoku)). The residential areas were also grouped into three categories according to population size (size of residential area: city with population ≥1 million; city with population <1 million or town and village). Current smoking (yes or no) was self-reported in the lifestyle questionnaire. Physical activity was computed as the average metabolic equivalents (MET)-hours per day[33] on the basis of the frequency and duration of five different activities (sleeping, high- and moderate-intensity activities, walking, and sedentary activities) over the preceding month, as reported in the lifestyle questionnaire.

Statistical analysis

Measures of dietary acid–base load, i.e. PRAL and Pro:K, were examined in relation to ten cardiometabolic risk factors, namely BMI, waist circumference, systolic and diastolic blood pressure, cholesterol (total, HDL, and LDL), fasting TAG, fasting glucose, and glycated Hb. All statistical analyses were performed using SAS statistical software (version 8.2; SAS Institute Inc., Cary, NC, USA). Linear regression models were constructed using the PROC GLM procedure to examine the association between dietary acid–base load measures with cardiometabolic risk factors. For the analyses, subjects were categorized into quintiles according to the dietary acid–base load measures. The mean metabolic risk factor values (with standard errors) were calculated by quintiles of dietary acid–base load measures after multivariate adjustment for potential confounding factors. Confounding factors included residential block, size of residential area, survey year (2006 or 2007; because of the different laboratories with different kits used for blood analyses for the 2006 and 2007 surveys, even though there were no differences in the assay methods), current smoking, and physical activity (continuous). BMI (continuous) was added as a confounding factor in all analyses except for that for BMI itself. Waist circumference (continuous) was also added as a confounding factor in the analyses except for those for BMI and waist circumference. We initially intended to include estimated excretion of OA (the diet-independent acid–base load) as a confounding factor to investigate diet-dependent acid–base load (PRAL and Pro:K) and cardiometabolic risk factors. However, OA was strongly correlated with body height and weight and hence BMI (Pearson correlation coefficient with OA = 0·70, 0·95, and 0·68, respectively), as OA is just a function of the combination of height and weight as mentioned earlier. To avoid over-adjustment, we consequently did not include OA as a confounding factor. Since alcohol intake was extremely low (mean = 1·5 g/d), it was not considered as a confounding factor. Because the inclusion of measures of obesity (BMI, waist circumference, or both) as confounding factors did not influence the results materially, we present the full-adjustment models only. Linear trends with increasing levels of dietary acid–base load measures were tested for by assigning each participant a median value for the category and modelling this value as a continuous variable. All reported P values are two-tailed, and a value of $P<0·05$ was considered statistically significant.

Results

Basic characteristics of all subjects (*n* 1136; those included in the analyses of BMI, waist circumference, and systolic and diastolic blood pressure) are shown in Table 1. Mean PRAL was 10·4 mEq/d, and mean Pro:K was 1·23 g/mEq. There was a strong correlation between these variables (Pearson correlation coefficient = 0·84). The potential confounding variables for all subjects are shown in Table 2 according to quintile of dietary acid–base load measure. Both PRAL and Pro:K were associated negatively with physical activity and positively with waist circumference. There was also a positive association between Pro:K and BMI. The dietary intakes of all subjects are shown in Table 3 according to quintile of dietary acid–base load measures. PRAL was associated positively with protein and negatively with K, Ca and Mg as well as P, while Pro:K was positively associated with K as well as protein. For foods, both PRAL and Pro:K showed a positive association with meats, eggs, cereals, and fish and shellfish, and a negative association with fruits, vegetables and dairy products. According to the quintiles of the dietary acid–base load measures, similar patterns were observed for potential confounding factors and dietary intake among those subjects included in the analyses of cholesterol (total, HDL, and LDL) and glycated Hb (*n* 1121), fasting TAG (*n* 1088), and fasting glucose (*n* 1089) (data not shown).

The multivariate-adjusted mean values for cardiometabolic risk factors across quintiles of dietary acid–base load

Table 1. Basic characteristics of subjects (*n* 1136)*
(Mean values and standard deviations)

	Mean	SD
Age (years)	19·6	1·1
Body height (cm)	158·4	5·5
Body weight (kg)	53·6	7·7
BMI (kg/m^2)	21·3	2·7
Waist circumference (cm)	72·9	7·1
Systolic blood pressure (mmHg)	106·4	10·6
Diastolic blood pressure (mmHg)	69·3	8·2
Total cholesterol (mg/l)	1889	318
HDL-cholesterol (mg/l)	706	127
LDL-cholesterol (mg/l)	1070	272
Fasting TAG (mg/l)	611	288
Fasting glucose (mg/l)	840	64
Glycated Hb (%)	4·87	0·26
Residential block (%)		
North (Kanto, Hokkaido, and Tohoku)	56	
Central (Tokai, Hokuriku, and Kinki)	24	
South (Kyushu and Chugoku)	20	
Size of residential area (%)		
City with population ≥1 million	16	
City with population <1 million	78	
Town and village	6	
Survey year (%)		
2006	41	
2007	59	
Current smoking (%)		
No	97	
Yes	3	
Physical activity (total MET-h/d)	33·9	3·1
Estimated urinary excretion of organic acid (mEq/d)	36·3	2·7
Energy intake (kJ/d)	7376	1874
Nutrient intake†		
Protein (g/d)	59·7	8·8
P (mg/d)	915	169
K (mg/d)	1971	471
Ca (mg/d)	502	171
Mg (mg/d)	213	49
Food intake (g/d)		
Meats	60·1	31·7
Fish and shellfish	50·3	28·6
Eggs	35·6	21·4
Dairy products	145·6	127·2
Fruits	57·9	57·3
Vegetables	206·9	121·2
Cereals	380·3	92·1
Measures of dietary acid–base load‡		
Potential renal acid load (mEq/d)	10·4	7·6
Pro:K (g/mEq)	1·23	0·22

MET, metabolic equivalents; Pro:K, ratio of dietary protein to K.
* *n* 1121 for cholesterol (total, HDL, and LDL) and glycated Hb; 1088 for fasting TAG; 1089 for fasting glucose.
† Energy-adjusted using the residual method.
‡ Calculated using crude nutrient intake values and then energy-adjusted using the residual method.

Table 2. Selected characteristics according to quintile of measures of dietary acid–base load (*n* 1136)
(Mean values and standard deviations)

	Quintile of measures of dietary acid–base load										
	1 (*n* 227)		2 (*n* 227)		3 (*n* 228)		4 (*n* 227)		5 (*n* 227)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P**
Potential renal acid load (mEq/d)†	−0·8	6·5	7·8	1·2	11·1	0·8	14·2	0·9	19·5	3·4	
Residential block (%)											0·69
North (Kanto, Hokkaido, and Tohoku)	57		55		54		57		58		
Central (Tokai, Hokuriku, and Kinki)	24		27		24		22		25		
South (Kyushu and Chugoku)	19		19		23		21		17		
Size of residential area (%)											0·036
City with population ≥1 million	16		15		13		15		22		
City with population <1 million	76		80		79		79		74		
Town and village	7		5		9		6		3		
Survey year (%)											0·86
2006	44		36		42		41		41		
2007	56		64		58		59		59		
Current smoking (%)											0·11
No	96		98		97		98		98		
Yes	4		2		3		2		2		
Physical activity (total mEq-h/d)	34·4	3·5	33·8	2·5	33·8	3·4	33·6	2·4	33·8	3·3	0·021
BMI (kg/m²)	21·1	2·6	21·2	3·2	21·5	2·5	21·6	2·6	21·3	2·7	0·11
Waist circumference (cm)	72·3	7·0	72·0	7·6	73·2	6·6	73·9	6·8	73·2	7·1	0·019
Pro:K (g/mEq)†	0·94	0·09	1·11	0·03	1·22	0·03	1·33	0·04	1·54	0·13	
Residential block (%)											0·14
North (Kanto, Hokkaido, and Tohoku)	56		57		60		55		51		
Central (Tokai, Hokuriku, and Kinki)	24		26		22		22		27		
South (Kyushu and Chugoku)	19		17		18		23		22		
Size of residential area (%)											0·084
City with population ≥1 million	15		14		16		18		18		
City with population <1 million	78		78		77		78		78		
Town and village	7		8		7		5		4		
Survey year (%)											0·31
2006	44		38		41		41		38		
2007	56		62		59		59		62		
Current smoking (%)											0·59
No	96		98		98		97		97		
Yes	4		2		2		3		3		
Physical activity (total MET-h/d)	34·4	3·6	34·0	2·6	33·7	2·6	34·1	3·9	33·4	2·2	0·002
BMI (kg/m²)	21·0	2·5	21·2	3·1	21·4	2·5	21·6	2·7	21·5	2·8	0·030
Waist circumference (cm)	72·1	7·0	72·2	7·4	72·8	6·3	73·8	7·0	73·6	7·4	0·002

MET, metabolic equivalents; Pro:K, ratio of dietary protein to K.
* For categorical variables, a Mantel–Haenszel χ^2 test was used; for continuous variables, a linear trend test was used with the median value in each quintile as a continuous variable in linear regression.
† Calculated using crude nutrient intake values and then energy-adjusted using the residual method.

measures are shown in Table 4. After adjustment for potential confounding factors, higher PRAL and Pro:K (more acidic dietary acid–base loads) were associated with higher systolic and diastolic blood pressure (mean difference between the lowest and highest quintiles = 2·1 mmHg (*P* for trend =0·028) and 1·6 mmHg (*P* for trend=0·035) for PRAL, and 2·5 mmHg (*P* for trend=0·012) and 2·3 mmHg (*P* for trend = 0·009) for Pro:K, respectively). In addition, PRAL showed an independent positive association with total and LDL cholesterol (mean difference = 59 mg/l (*P* for trend=0·042) and 60 mg/l (*P* for trend=0·021), respectively). Pro:K was positively associated with BMI and waist circumference independently of potential confounding factors (mean difference = 0·5 kg/m² (*P* for trend=0·024) and 0·8 cm (*P* for trend=0·012), respectively). No significant associations were observed between PRAL or Pro:K and any of the other cardiometabolic risk factors examined.

Discussion

In a group of free-living young Japanese women, we found that higher PRAL and Pro:K (more acidic dietary acid–base loads) were associated with higher systolic and diastolic blood pressure after adjustment for possible confounding factors. We also found independent positive associations between PRAL and total and LDL-cholesterol, as well as between Pro:K and BMI and waist circumference. To our knowledge, this is the first study to examine the relationships between dietary acid–base load measures and cardiometabolic risk factors.

Consistent with previous studies[19–21], the correlation between PRAL and Pro:K was quite high (Pearson correlation coefficient = 0·84–0·93), which indicates that these measures capture similar, but not the same, elements of dietary acid–base load. Given that only blood pressure was