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Applied nutritional investigation

Dietary energy density is associated with body mass index and waist circumference, but not with other metabolic risk factors, in free-living young Japanese women

Kentaro Murakami, M.Sc.[a,b], Satoshi Sasaki, M.D., Ph.D.[a,c,*], Yoshiko Takahashi, Ph.D.[a,d], and Kazuhiro Uenishi, Ph.D.[e], for the Japan Dietetic Students' Study for Nutrition and Biomarkers Group

[a] *Nutritional Epidemiology Program, National Institute of Health and Nutrition, Tokyo, Japan*
[b] *Department of Epidemiology and International Health, Research Institute, International Medical Center of Japan, Tokyo, Japan*
[c] *Department of Social and Preventive Epidemiology, School of Public Health, The University of Tokyo, Tokyo, Japan*
[d] *Department of Health and Nutrition, School of Home Economics, Wayo Women's University, Chiba, Japan*
[e] *Laboratory of Physiological Nutrition, Kagawa Nutrition University, Saitama, Japan*

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Abstract

Objective: Little is known about the relation of dietary energy density (kilocalories per gram) to metabolic risk factors, particularly in young adults and non-Western populations. We examined the cross-sectional associations between dietary energy density and several metabolic risk factors in free-living young Japanese women.

Methods: The subjects were 1136 female Japanese dietetic students 18–22 y of age. Dietary energy density was estimated based on foods only, using a self-administered diet history questionnaire; before the present analysis, this measurement was validated against 16-d weighed dietary records in 92 Japanese women 31–69 y of age (Pearson's correlation coefficient 0.52). Body height and weight, from which body mass index (BMI) was derived, waist circumference, and blood pressure were measured, and fasting blood samples were collected for biochemical measurements.

Results: Mean BMI was 21.3 kg/m^2 (standard deviation 2.7), mean waist circumference was 72.9 cm (standard deviation 7.1), and mean dietary energy density was 1.41 kcal/g (standard deviation 0.23). After adjustment for potential confounding factors, dietary energy density was positively associated with BMI (P for trend = 0.004). Dietary energy density also showed an independent and positive association with waist circumference (P for trend <0.0001). No significant associations were observed between dietary energy density and any of the other metabolic risk factors examined.

Conclusion: Dietary energy density was independently and positively associated with BMI and waist circumference, but not with other metabolic risk factors, in free-living young Japanese women who are not only lean but whose dietary energy density is also low compared with Western populations.

Keywords: Energy density; Metabolic risk factors; Body mass index; Waist circumference; Diet history questionnaire; Young Japanese women

Introduction

Energy density is defined as the amount of energy in a given weight of food (kilocalories per gram). Because people tend to consume a fairly consistent weight of food, rather than a consistent energy content [1–3], dietary energy density might play an important role in regulating energy balance and thus in body weight and adiposity [4]. Actually, several [5–12], but not all [13–15], cross-sectional observational studies of free-living adult populations have shown the positive association of dietary energy density with measurements of obesity, although the sole prospective study

* Corresponding author. Tel.: +81-3-3203-8064; fax: +81-3-3202-3278.
E-mail address: stssasak@nih.go.jp (S. Sasaki).

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failed to find an association between dietary energy density and 5-y weight change [16]. Additionally, because energy-dense diets are generally associated with unfavorable dietary intake patterns [11,17], they may contribute to adverse profiles of other metabolic risk factors, independent of obesity, by virtue of such dietary patterns [18] including higher levels of fat [19] and lower levels of dietary fiber [20] and fruits and vegetables [21]. A cross-sectional analysis has actually shown the positive association between dietary energy density and metabolic syndrome [12].

However, information on the relation of dietary energy density to obesity and other metabolic risk factors is lacking among young adult populations. Because the adverse profile of metabolic risk factors, characterized by the metabolic syndrome, is an independent predictor of cardiovascular diseases [22,23] and type 2 diabetes [22,24], the identification of modifiable lifestyle factors associated with metabolic risk factors, e.g., dietary energy density, in young adult populations is vitally important from a preventive perspective.

Additionally, associations of dietary energy density with metabolic risk factors have been poorly investigated in non-Western populations, including the Japanese [5,15]. Boiled rice contributes the greatest total energy to the Japanese diet (29%) [25], with a relatively low energy density (1.68 kcal/g) [26] mainly because of high water concentration (60%) [26]. Further, fat intake is relatively low (≤30% energy) [27] mainly because of low consumption of fats and oils (accounting for 4.5% energy) [25], foods with the highest energy density (9 kcal/g). Because these characteristics are seldom observed in Westerners, a different association of dietary energy density and metabolic risk factors may exist between Western and Japanese populations.

Therefore, the aim of this cross-sectional study of young Japanese women was to investigate the associations of dietary energy density with several metabolic risk factors, including body mass index (BMI); waist circumference; systolic and diastolic blood pressures; total, high-density lipoprotein (HDL), and low-density lipoprotein (LDL) cholesterol; triacylglycerol; glucose; and glycated hemoglobin.

Materials and methods

The present study was based on a cross-sectional multicenter survey conducted from February to March 2006 and from January to March 2007 among female dietetic students from 15 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 <20 y of age. A total of 1176 Japanese women took part. For the present analysis, women 18–22 y of age were selected (n = 1154). We then excluded women not completing survey questionnaires (n = 1), those with extremely low or high reported energy intakes (<500 or >4000 kcal/d, n = 2), those currently receiving dietary counseling from a doctor or dietitian (n = 13), those with previously diagnosed diabetes, hypertension, or cardiovascular disease (n = 1), and those without measurement of body height and weight (n = 2). Additionally, women providing non-fasting blood samples (n = 34) and those with missing information on any of metabolic risk factors (n = 16) were excluded from the analyses of biochemical measurements. Some women fell into more than one exclusion category. The final sample sizes were 1136 for BMI, waist circumference, and systolic and diastolic blood pressures and 1087 for cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin.

Dietary habits during the preceding month were assessed using a validated, self-administered, comprehensive, diet history questionnaire (DHQ) [28–30]. Responses to the DHQ and those to an accompanying 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 16-page structured questionnaire that consists of the following seven sections: general dietary behavior; major cooking methods; consumption frequency and amount of six alcoholic beverages; consumption frequency and semiquantitative portion size of 118 selected food and non-alcoholic beverage items; dietary supplements; consumption frequency and semiquantitative portion size of 19 cereals (rice, bread, and noodles), soup consumed with noodles, and miso (fermented soybean paste) soup; and open-ended items for foods consumed regularly (at least once per week) but not appearing in the DHQ [28]. 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 portions were derived mainly from several recipe books for Japanese dishes [28]. Estimates of dietary intake for a total of 150 food and beverage items (including five seasonings), energy, and selected nutrients were calculated using an ad hoc computer algorithm for the DHQ, which was 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 [28]. Nutrient and food intakes were energy adjusted using the density method, i.e., percentage of energy for energy-providing nutrients and amounts per 1000 kcal of energy for other nutrients and foods. Detailed description of the validity of the DHQ with respect to commonly studied nutritional factors and the methods used to calculate dietary intake have been published elsewhere [28–30]. For example, Pearson's correlation coefficients between the DHQ and 3-d estimated dietary records were 0.48 for energy, 0.48 for protein, 0.55 for fat, and 0.48 for carbohydrate in 47 women [28].

Using dietary intake information estimated from the DHQ as described above, dietary energy density was calculated by dividing each subject's reported energy intake (kilocalories per day) by the reported weight of foods consumed (grams per day), based on foods only (128 items); excluded from the calculation were caloric and non-caloric beverages (fruit and vegetable juice, four items; soft drinks, four items; milks, three items; alcoholic beverages, six items; tea, two items; coffee, one item; diet drinks, one item; and drinking water, one item) [31]. Before the present analysis, the relative validity of dietary energy density estimated from the DHQ was examined against that from the 16-d weighed dietary records in 92 women 31–69 y of age. A total of 1299 food and beverage items appeared in the 16-d dietary records. Using dietary intake information estimated from the 16-d dietary records based on the Standard Tables of Food Composition in Japan [26], dietary energy density was similarly calculated by dividing reported energy intake (kilocalories per day) by the reported weight of foods consumed (grams per day), based on foods only (1186 items); excluded from the calculation were caloric and non-caloric beverages (fruit and vegetable juice, 35 items; soft drinks, 11 items; milks, 18 items; alcoholic beverages, 32 items; tea, 13 items; coffee, 3 items; and drinking water, 1 item; diet drinks did not appear) [31]. Pearson's correlation coefficient between the two methods was 0.52 (unpublished observations, S. Sasaki, 2006), which is comparable to the only previous study to calculate dietary energy density from dietary questionnaire data (0.32–0.60) [8]. This method of calculating dietary energy density has been shown to provide the best correlations with measurements of obesity in previous analyses of American adults [11]. Alternative methods of calculating dietary energy density, based on the inclusion of beverages, were associated with higher variance ratios, which may diminish associations when examining health outcomes [31]. The inclusion of beverages, whether caloric or not, in energy density calculations may have a disproportionate influence on individual values, because beverages have a much lower energy density than foods [31]. Additionally, the inclusion of beverages in energy density calculation resulted in the lower correlation of dietary energy density between our DHQ and dietary records (unpublished observations, S. Sasaki, 2006).

Metabolic 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 (kilograms) divided by the square of body height (meters). 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 pressures were 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 $\geq$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 hemoglobin 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 2006 and Mitsubishi Kagaku Bio-Clinical Laboratories Inc. in 2007). All biochemical variables used in the present study were assayed at the laboratory within 1–2 d of collection to avoid significant degradation. Serum total, LDL, and HDL cholesterol, triacylglycerol, and glucose concentrations were measured by enzymatic assay methods. Glycated hemoglobin was measured by latex agglutination-turbidimetric immunoassay. In-house quality-control procedures for all assays were conducted at the respective laboratory.

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 $\geq$1 million, city with population $<$1 million, or town and village). Current smoking (yes or no) was self-reported on the lifestyle questionnaire. Rate of eating was self-reported as part of the DHQ according to one of five qualitative categories (very slow, relatively slow, medium, relatively fast, and very fast). This variable was significantly and directly associated with BMI in a previous study of 18-y-old Japanese women [32]. Because relatively few subjects were categorized into the extreme categories (very slow and very fast) in the present study, they were included in their adjacent categories (relatively slow and relatively fast, respectively), and the three categories (slow, medium, or fast) were consequently used. Subjects also reported on the lifestyle questionnaire the time they usually got up and went to bed, which was used to calculate sleeping hours, and the frequency and duration of high-intensity activities (e.g., carrying heavy loads; bicycling, moderate effort; jogging; and singles tennis), moderate-intensity activities (e.g., carrying light loads; bicycling, light effort; and doubles tennis), walking, and sedentary activities (e.g., studying; reading; and watching television) during the preceding month. Each activity was assigned a metabolic equivalent value from a previously published table (0.9 for sleeping, 1.5 for sedentary activity, 3.3 for walking, 5.0 for moderate-intensity activity, and 7.0 for high-intensity activity) [33]. The number of hours spent per day on each activity was multiplied by the metabolic equivalent value of that activity, and all metabolic equivalent-hour products were summed to produce a total metabolic equivalent-hour score for the day, which was used as a measurement of physical activity. The ratio of total energy intake to estimated energy expenditure was used as a measurement of dietary intake misreporting. Energy expenditure can be estimated as basal metabolic rate multiplied by an appropriate physical activity level value [34]. Basal metabolic rate was estimated using measured body weight according to the FAO/WHO/UNU equation for women 18–30 y of age [35]. The basal metabolic rate calculated from the Food and Agriculture Organization/World Health Organization/United Nations University equations was relatively comparable to the measured basal metabolic rate in Japanese people at the group level (means 1182 and 1107 kcal/d, respectively) [36]. In the absence of an accurate and comprehensive measurement of physical activity, we could not assign each subject an appropriate physical activity level value. In our sample, self-reported time spent on sedentary activities was predominant compared with that spent on high-intensity activities, moderate-intensity activities, and walking (means 16.46, 0.06, 0.24, and 0.44 h/d, respectively), indicating a predominantly sedentary lifestyle. We thus estimated energy expenditure as estimated basal metabolic rate by physical activity level value for light activity (1.56) [35].

Dietary energy density was examined in relation to 10 metabolic risk factors, namely BMI, waist circumference, systolic and diastolic blood pressures, cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin. All statistical analyses were performed using SAS 8.2 (SAS Institute, Cary, NC, USA). Linear regression models were constructed using the PROC GLM procedure to examine the association between dietary energy density with metabolic risk factors. For the analyses, subjects were categorized into quartiles according to dietary energy density. The mean ± standard error metabolic risk factor values were calculated by quartiles of dietary energy density 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 used for blood analyses for the 2006 and 2007 surveys, even though there were no differences in the assay methods), current smoking, rate of eating, physical activity (continuous), and the ratio of total energy intake to estimated energy expenditure (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. Because the inclusion of measurements of obesity (BMI and/or waist circumference) as confounding factors did not influence the results materially, we present the full-adjustment models only. Linear trends with increasing levels of dietary energy density were tested for by assigning each participant a median value for the category and modeling this value as a continuous variable. All reported P values are two-tailed, and $P < 0.05$ 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 pressures) are presented in Table 1. Mean BMI was 21.3 kg/m^2, mean waist circumference was 72.9 cm, and mean dietary energy density was 1.41 kcal/g. The potential confounding variables for all subjects are listed in Table 2 according to quartile of dietary energy density. There was a positive association of dietary energy density with rate of eating and the ratio of total energy intake to estimated energy expenditure. Dietary energy density was also positively associated with BMI and waist circumference. The dietary intakes of all subjects are reported in Table 3 according to quartile of dietary energy density. Dietary energy density was associated positively with energy intake and negatively with amount of foods consumed. For nutrients, dietary energy density was associated positively with fat and negatively with water, dietary fiber, protein, and carbohydrate. For foods, dietary energy density was associated positively with bread, sugar and confectionaries, and fats and oils, and negatively with fruits and vegetables, noodles, rice, and meats and fish. According to the quartile of dietary energy density, similar patterns were observed for potential confounding factors and dietary intake among those subjects included in the analyses of cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin (n = 1087, data not shown). The multivariate-adjusted mean values for met-

Table 1
Basic characteristics of subjects (n = 1136)*

Variable	
Age (y)	19.6 ± 1.1
Body height (cm)	158.4 ± 5.5
Body weight (kg)	53.6 ± 7.7
Body mass index (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/dL)	189.1 ± 31.6
HDL cholesterol (mg/dL)	70.7 ± 12.7
LDL cholesterol (mg/dL)	107.1 ± 27.0
Triacylglycerol (mg/dL)	61.1 ± 28.8
Glucose (mg/dL)	84.1 ± 6.4
Glycated hemoglobin (%)	4.87 ± 0.26
Dietary energy density (kcal/g)†	1.41 ± 0.23

HDL, high-density lipoprotein; LDL, low-density lipoprotein

* Values are means ± SDs; n = 1087 for cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin.

† Calculated based on foods only; excluded from the calculation were caloric and non-caloric beverages (fruit and vegetable juices, soft drinks, milks, alcoholic beverages, tea, coffee, diet drinks, and drinking water).

Table 2
Selected characteristics according to quartile of dietary energy density (n = 1136)*

Variable	All (n = 1136)	Quartiles of dietary energy density (median)				$P^{\dagger}$
		1 (1.16 kcal/g) (n = 284)	2 (1.32 kcal/g) (n = 284)	3 (1.46 kcal/g) (n = 284)	4 (1.67 kcal/g) (n = 284)	
Residential block						0.70
North (Kanto, Hokkaido, and Tohoku)	636 (56)	161 (57)	162 (57)	163 (57)	150 (53)	
Central (Tokai, Hokuriku, and Kinki)	275 (24)	66 (23)	66 (23)	62 (22)	81 (29)	
South (Kyushu and Chugoku)	225 (20)	57 (20)	56 (20)	59 (21)	53 (19)	
Size of residential area						0.18
City with population ≥1 million	183 (16)	43 (15)	45 (16)	52 (18)	43 (15)	
City with population <1 million	883 (78)	216 (76)	224 (79)	212 (75)	231 (81)	
Town and village	70 (6)	25 (9)	15 (5)	20 (7)	10 (4)	
Survey year						0.003
2006	461 (41)	131 (46)	117 (41)	119 (42)	94 (33)	
2007	675 (59)	153 (54)	167 (59)	165 (58)	190 (67)	
Current smoking						0.80
No	1107 (97)	275 (97)	281 (99)	272 (96)	279 (98)	
Yes	29 (3)	9 (3)	3 (1)	12 (4)	5 (2)	
Rate of eating						0.021
Slow	343 (30)	93 (33)	81 (29)	93 (33)	76 (27)	
Medium	344 (30)	102 (36)	86 (30)	71 (25)	85 (30)	
Fast	449 (40)	89 (31)	117 (41)	120 (42)	123 (43)	
Physical activity (total metabolic equivalents-hours/d)	33.9 ± 3.1	34.2 ± 3.2	33.7 ± 2.4	34.0 ± 3.8	33.7 ± 2.7	0.25
Ratio of total energy intake to estimated energy expenditure	0.88 ± 0.23	0.86 ± 0.23	0.87 ± 0.20	0.89 ± 0.21	0.92 ± 0.27	0.002
Body mass index (kg/m^2)	21.3 ± 2.7	21.1 ± 3.1	21.2 ± 2.5	21.5 ± 2.8	21.6 ± 2.5	0.033
Waist circumference (cm)	72.9 ± 7.1	71.7 ± 7.5	72.5 ± 6.0	73.6 ± 7.1	73.9 ± 7.4	<0.0001

* Values are numbers of subjects (%) or means ± SDs. Dietary energy density was calculated based on foods only; excluded from the calculation were caloric and non-caloric beverages (fruit and vegetable juices, soft drinks, milks, alcoholic beverages, tea, coffee, diet drinks, and drinking water).

† For categorical variables, a Mantel-Haenszel chi-square test was used; for continuous variables, a linear trend test was used with the median value in each quartile as a continuous variable in linear regression.

abolic risk factors across quartiles of dietary energy density are listed in Table 4. After adjustment for potential confounding factors, dietary energy density was positively associated with BMI (mean difference between the lowest and highest quartiles 0.6 kg/m^2, P for trend = 0.004). Dietary energy density also showed an independent and positive association with waist circumference (mean difference 1.7 cm, P for trend <0.0001). No significant associations were observed between dietary energy density and any of the other metabolic risk factors examined.

Discussion

We found that dietary energy density was independently and positively associated with BMI and waist circumference, but not with other metabolic risk factors, in a group of young Japanese women who are not only lean but whose dietary energy density is also low compared with Western populations [11,12,31]. To our knowledge, this is the first study to examine the relations between dietary energy density and metabolic risk factors in young adult populations.

Our mean estimate of dietary energy density (calculated based on foods only, 1.41 kcal/g) was considerably lower than that observed in Western studies (1.79–1.85 kcal/g) [11,12,31]. This may be due to higher consumption of rice and noodles (foods high in water content) accompanied by lower intake of energy-dense foods such as fats and oils and sugar and confectionaries in our subjects than in Western populations [11,17]. Lower dietary energy density was associated with more favorable dietary intake patterns in the present study, including higher intake of dietary fiber and fruits and vegetables and lower intake of dietary energy and fat, fats and oils, and sugar and confectionaries, which is generally consistent with previous Western studies [11,17]. However, major contributors to dietary energy density seem to differ between Asian and Western populations. Although water intake and fat intake were 77% higher and 11% lower, respectively, in the lowest than in the highest quartiles of dietary energy density in our Japanese population, fat intake was about 20% lower in the lowest than in the highest tertiles of dietary energy density in Western adults (data not available for water) [11,17]. In a Chinese population, only water had a strong influence on dietary energy density [5]. Thus, it is speculated that low energy-dense diets in Asian populations are characterized mainly by higher consump-

Table 3
Dietary intake according to quartile of dietary energy density (n = 1136)*

Variable	All (n = 1136)	Quartiles of dietary energy density (median)				P for trend†
		1 (1.16 kcal/g) (n = 284)	2 (1.32 kcal/g) (n = 284)	3 (1.46 kcal/g) (n = 284)	4 (1.67 kcal/g) (n = 284)	
Energy intake (kcal/d)	1640 ± 417	1568 ± 381	1611 ± 359	1658 ± 399	1724 ± 501	<0.0001
Amount of foods consumed (g/d)	1187 ± 325	1383 ± 341	1221 ± 275	1132 ± 275	1010 ± 286	<0.0001
Nutrient intake						
Protein (% energy)	13.3 ± 1.9	14.3 ± 1.9	13.6 ± 1.7	13.0 ± 1.6	12.4 ± 1.8	<0.0001
Fat (% energy)	29.4 ± 5.4	27.8 ± 4.8	28.4 ± 4.9	30.2 ± 5.3	31.3 ± 5.9	<0.0001
Carbohydrate (% energy)	56.0 ± 6.1	57.0 ± 5.9	56.7 ± 5.7	55.3 ± 5.9	54.8 ± 6.8	<0.0001
Water (g/1000 kcal)	511 ± 116	663 ± 76	539 ± 25	466 ± 24	374 ± 49	<0.0001
Dietary fiber (g/1000 kcal)	7.1 ± 2.1	9.1 ± 2.3	7.3 ± 1.4	6.4 ± 1.3	5.7 ± 1.2	<0.0001
Food intake (g/1000 kcal)						
Rice	167.7 ± 66.1	174.7 ± 60.0	178.0 ± 57.4	164.9 ± 67.4	153.2 ± 75.4	<0.0001
Bread	20.2 ± 16.8	13.5 ± 11.4	17.4 ± 12.6	21.6 ± 17.7	28.4 ± 20.4	<0.0001
Noodles	40.9 ± 34.4	51.0 ± 41.7	44.9 ± 35.7	40.5 ± 29.5	27.4 ± 23.7	<0.0001
Sugar and confectioneries	55.2 ± 23.7	44.0 ± 17.8	49.8 ± 18.2	58.7 ± 23.9	68.2 ± 26.3	<0.0001
Fats and oils	12.7 ± 5.7	12.1 ± 5.2	11.9 ± 4.9	13.4 ± 6.2	13.2 ± 6.4	0.004
Fruits and vegetables	160.6 ± 85.0	245.2 ± 101.5	168.0 ± 55.3	131.6 ± 45.4	97.7 ± 38.3	<0.0001
Meats and fish	66.0 ± 25.2	70.4 ± 25.3	67.9 ± 24.3	65.7 ± 23.2	59.9 ± 26.8	<0.0001

* Values are means ± SDs. All dietary variables were calculated based on foods only; excluded from the calculation were caloric and non-caloric beverages (fruit and vegetable juices, soft drinks, milks, alcoholic beverages, tea, coffee, diet drinks, and drinking water).

† A linear trend test was used with the median value in each quartile as a continuous variable in linear regression.

tion of foods high in water content (hence energy-dilute foods), whereas these in Western populations are characterized mainly by lower consumption of foods high in fat content (hence, energy-dense foods). This important point of difference between Western and Asian populations needs to be investigated in future studies.

Dietary energy density was independently associated with BMI and waist circumference in this group of lean young Japanese women. Several cross-sectional studies in Western countries have found lower dietary energy density values to be associated with a more favorable BMI [6–12] and waist circumference [12], whereas other have not sup-

Table 4
Metabolic risk factors according to quartile of dietary energy density (n = 1136)*

Variable	Quartiles of dietary energy density (median)				P for trend†
	1 (1.16 kcal/g) (n = 284)	2 (1.32 kcal/g) (n = 284)	3 (1.46 kcal/g) (n = 284)	4 (1.67 kcal/g) (n = 284)	
Body mass index (kg/m^2)‡	21.1 ± 0.2	21.1 ± 0.2	21.5 ± 0.2	21.7 ± 0.2	0.004
Waist circumference (cm)‡§	72.0 ± 0.3	72.7 ± 0.3	73.3 ± 0.3	73.7 ± 0.3	<0.0001
Systolic blood pressure (mmHg)‡§‖	106.5 ± 0.6	106.3 ± 0.6	107.0 ± 0.6	105.8 ± 0.6	0.54
Diastolic blood pressure (mmHg)‡§‖	69.5 ± 0.5	69.2 ± 0.4	70.0 ± 0.5	68.6 ± 0.5	0.32
Total cholesterol (mg/dL)‡§‖	188.3 ± 1.9	187.6 ± 1.9	190.7 ± 1.9	189.7 ± 1.9	0.42
HDL cholesterol (mg/dL)‡§‖	70.0 ± 0.8	70.9 ± 0.8	70.8 ± 0.8	71.2 ± 0.8	0.31
LDL cholesterol (mg/dL)‡§‖	106.7 ± 1.6	104.8 ± 1.6	108.5 ± 1.6	108.2 ± 1.6	0.28
Triacylglycerol (mg/dL)‡§‖	60.1 ± 1.7	60.0 ± 1.7	64.5 ± 1.7	59.9 ± 1.7	0.75
Glucose (mg/dL)‡§‖	83.8 ± 0.4	83.8 ± 0.4	84.5 ± 0.4	84.2 ± 0.4	0.34
Glycated hemoglobin (%)‡§‖	4.85 ± 0.02	4.87 ± 0.02	4.87 ± 0.02	4.88 ± 0.02	0.16

HDL, high-density lipoprotein; LDL, low-density lipoprotein

* Values are adjusted means ± SEs; n = 1087 for cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin (271 in the first quartile and 272 in the second, third, and fourth quartiles). The median value of dietary energy density in each quartile is the same. Dietary energy density was calculated based on foods only; excluded from the calculation were caloric and non-caloric beverages (fruit and vegetable juices, soft drinks, milks, alcoholic beverages, tea, coffee, diet drinks, and drinking water).

† A linear trend test was used with the median value in each quartile as a continuous variable in linear regression.

‡ Adjusted for residential block (north [Kanto, Hokkaido, and Tohoku], central [Tokai, Hokuriku, and Kinki], or south [Kyushu and Chugoku]), size of residential area (city with population ≥1 million, city with population with <1 million, or town and village), survey year (2006 or 2007), current smoking (yes or no), rate of eating (slow, medium, or fast), physical activity (total metabolic equivalents-hours per day, continuous), and ratio of total energy intake to estimated energy expenditure (continuous).

§ Also adjusted for body mass index (continuous).

‖ Also adjusted for waist circumference (continuous).

ported such an association [13,14]. Among Chinese populations, one study observed a positive association between dietary energy density and BMI [5], but another found no relation with the percentage of body fat [15]. The sole prospective study, where diet was assessed at baseline only, failed to find an association between dietary energy density and 5-y weight change [16]. Potential explanations for the inconsistent findings may be differences in the populations examined, dietary assessment methods used, and number and type of variables used as confounding factors. However, because these studies used different (or unclear) schemes to include beverages in the calculation of dietary energy density, comparison of these results may be difficult. Not only because inclusion of beverages when calculating dietary energy density may weaken associations with outcome measures owing to increased within-person variation [31], but also because the inclusion of beverages in energy density calculation lowered the correlation of dietary energy density between our DHQ and dietary records (unpublished observations, S. Sasaki, 2006), we used in the present study dietary energy density calculated based on foods only. Previous studies using dietary energy density based on food only have consistently shown a positive association with BMI [10–12] and waist circumference [12], which is in agreement with our findings.

A very recent cross-sectional study of American adults has shown positive associations of dietary energy density (based on foods only) with fasting insulin and the prevalence of metabolic syndrome, but not with glycated hemoglobin and fasting glucose (data not available for other factors) [12]. In our population of lean young Japanese women, dietary energy density was not associated with diastolic blood pressure, cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin (data not available for insulin). Dietary energy density might not have an influence on metabolic risk factors except for obesity in lean and young populations. Further research on this important public health issue is warranted.

Several limitations of the present study warrant mention. First, the cross-sectional nature of the study does not permit the assessment of causality owing to the uncertain temporality of the association. We cannot rule out the possibility that the diet and obesity links observed are due to post hoc changes in dietary behavior as a consequence of obesity, although it is unlikely that people consume unhealthier diets (e.g., energy-dense diets) as a result of obesity. Therefore, a prospective study or trial should be undertaken to confirm the relation between dietary energy density and metabolic risk factors. Second, our subjects were selected female dietetic students, not a random sample of Japanese women. In addition, because of our recruitment procedure, the exact response rate was unknown, which might have produced recruitment bias. Thus, these results may not apply to the general Japanese population, although our population was on average comparable to a representative sample of Japanese women 20–29 y of age, at least with regard to several metabolic risk factors including BMI (20.9 kg/m^2), systolic blood pressure (108.8 mmHg), diastolic blood pressure (67.0 mmHg), total cholesterol (180.6 mg/dL), HDL cholesterol (68.9 mg/dL), and glycated hemoglobin (4.91%; data not available for other metabolic risk factors and dietary energy density) [27]. Further, because the study population consisted of generally healthy persons, the clinical relevance of our findings remains to be elucidated. Nevertheless, our results should provide valuable insight from a prevention perspective. Third, a self-administered semi-quantitative dietary assessment questionnaire (i.e., DHQ) was used to collect dietary data [28–30]. Because actual dietary habits were not observed, the results should be interpreted with caution. However, the correlation between DHQ and dietary records for dietary energy density was reasonable and comparable to the only previous study to calculate dietary energy density from dietary questionnaire data [8], suggesting the applicability of the DHQ in energy density research. Additionally, the misreporting of dietary intake, particularly by overweight subjects, is a serious problem associated with self-report dietary assessment methods [37]. To minimize possible influence of dietary misreporting, we included the ratio of total energy intake to estimated energy expenditure as a confounding factor in the models. Although consistent misreporting across all types of foods would likely have little influence on dietary energy density values [10], studies have indicated that overweight persons may selectively under-report their intake of fatty or sugary foods [38,39], which could cause dietary energy density estimations to be lower than actual values. However, although potential selective under-reporting by subjects with a high BMI or waist circumference would likely have weakened associations of dietary energy density with measurements of obesity and possibly to a null finding, we did find significant associations between dietary energy density and both BMI and waist circumference. Fourth, although adjustments were attempted to compensate for a variety of potential confounding variables, residual confounding could not be ruled out. In particular, physical activity was assessed relatively roughly from only five activities, which may not have been sufficient.

Conclusions

Dietary energy density was independently associated with BMI and waist circumference, but not with other metabolic risk factors, in young Japanese women. Because the cross-sectional nature of our study precludes causal inferences, any firm conclusions regarding the effects of dietary energy density on metabolic risk factors will require additional studies.

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Appendix

The members of the Japan Dietetic Students' Study for Nutrition and Biomarkers Group (in addition to the authors) are as follows: Mitsuyo Yamasaki, Yuko Hisatomi, Junko Soezima, and Kazumi Takedomi (Nishikyushu University); Toshiyuki Kohri and Naoko Kaba (Kinki University); Etsuko Uneoka (Otemae College of Nutrition); Hitomi Hayabuchi and Yoko Umeki (Fukuoka Women's University); Keiko Baba and Maiko Suzuki (Mie Chukyo University Junior College); Reiko Watanabe and Kanako Muramatsu (Niigata Women's College); Kazuko Ohki, Seigo Shiga, Hidemichi Ebisawa, and Masako Fuwa (Showa Women's University); Tomoko Watanabe, Ayuho Suzuki, and Fumiyo Kudo (Chiba College of Health Science); Katsumi Shibata, Tsutomu Fukuwatari, and Junko Hirose (The University of Shiga Prefecture); Toru Takahashi and Masako Kato (Mimasaka University); Toshinao Goda and Yoko Ichikawa (University of Shizuoka); Junko Suzuki, Yoko Niida, Satomi Morohashi, Chiaki Shimizu, and Naomi Takeuchi (Hokkaido Bunkyo University); Jun Oka and Tomoko Ide (Tokyo Kasei University); and Yoshiko Sugiyama and Mika Furuki (Minamikyushu University).

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ORIGINAL ARTICLE

Dietary fiber intake, dietary glycemic index and load, and body mass index: a cross-sectional study of 3931 Japanese women aged 18–20 years

K Murakami[1], S Sasaki[1], H Okubo[2], Y Takahashi[1], Y Hosoi[1], M Itabashi[1], and the Freshmen in Dietetic Courses Study II Group[3]

[1]*Nutritional Epidemiology Program, National Institute of Health and Nutrition, Tokyo, Japan and* [2]*Department of Nutrition Sciences, Kagawa Nutrition University, Saitama, Japan*

Objective: Few observational studies have investigated dietary fiber intake and dietary glycemic index (GI) and glycemic load (GL) simultaneously in relation to obesity, particularly in non-Western populations. We examined the associations between dietary fiber intake and dietary GI and GL, and body mass index (BMI) in young Japanese women.
Design: Cross-sectional study.
Subjects: A total of 3931 female Japanese dietetic students aged 18–20 years from 53 institutions in Japan.
Methods: Dietary fiber intake and dietary GI and GL (GI for glucose = 100) were assessed by a validated, self-administered, diet history questionnaire. BMI was calculated from self-reported body weight and height.
Results: Mean values of BMI, dietary fiber intake, dietary GI and dietary GL were 21.0 kg/m^2, 6.5 g/4186 kJ, 65.1 and 82.1/4186 kJ, respectively. White rice (GI = 77) was the major contributor to dietary GI and GL (45.8%). After controlling for potential dietary and nondietary confounding factors, dietary fiber intake was negatively correlated with BMI (adjusted mean = 21.1 kg/m^2 in the lowest and 20.7 kg/m^2 in the highest quintiles; P for trend = 0.0007). Conversely, dietary GI and GL were independently positively correlated with BMI (20.8 and 21.2 kg/m^2; P for trend = 0.03, and 20.5 and 21.5 kg/m^2; P for trend = 0.0005, respectively).
Conclusions: Dietary fiber intake showed an independent negative association with BMI, and dietary GI and GL showed an independent positive association with BMI among relatively lean young Japanese women.
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Keywords: dietary fiber intake; dietary glycemic index; dietary glycemic load; body mass index; Japanese women; epidemiology

Correspondence: Dr S Sasaki, National Institute of Health and Nutrition, Toyama 1-23-1, Shinjuku-ku, Tokyo 162-8636, Japan.
E-mail: stssasak@nih.go.jp

[3]Other members of the Freshmen in Dietetic Courses Study II Group have been listed previously in Murakami K, Sasaki S, Okubo H, Takahashi Y, Hosoi Y, Itabashi M, the Freshmen in Dietetic Courses Study II Group (2006a). Association between dietary fiber, water, and magnesium intake and functional constipation among young Japanese women. *Eur J Clin Nutr* (advance online publication, 6 December 2006; doi:10.1038/sj.ejcn.1602573).

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Contributors: KM was involved in the study designing, data collection and data management, conducted the statistical analyses, and wrote the manuscript. SS was responsible for the study designing, data collection, data management, and the overall management and assisted in the manuscript preparation. HO was involved in the study designing. YT assisted in the manuscript preparation. YH was involved in the study designing, data collection and data management. MI was involved in data collection and data management. All the authors provided suggestions during the preparation of the manuscript and approved the final version submitted for publication.

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Introduction

Dietary fat intake has long been assumed to be a major nutritional contributing factor to obesity, but the results of observational studies have been mixed (Appleby *et al.* , 1998; Ludwig *et al.*, 1999; Stookey, 2001; Sasaki *et al.*, 2003; Spencer *et al.*, 2003; Howarth *et al.*, 2005). Although this inconsistency may be due to selective underestimation of dietary fat intake by obese people (Goris *et al.*, 2000), the potential role of dietary carbohydrate in the development of obesity has thus become an important question, because the intake of another macronutrient, protein, is fairly constant in normal diets.

Dietary carbohydrate is typically divided into simple sugar and complex carbohydrate on the basis of their degree of polymerization. Their effects on health, however, may be better described according to their physiological effects, specifically, their ability to raise blood glucose (Augustin *et al.*, 2002), because the blood glucose response varies substantially among different carbohydrate-containing foods, and cannot be predicted by their chemical composition (Wolever, 1990). This different glycemic response is quantified according to the glycemic index (GI), which is a measure of how much each available carbohydrate-containing food raises blood glucose in comparison with a standard food of either glucose or white bread (per 50 g of available carbohydrate) (Jenkins *et al.*, 1981). In consideration of the amounts of carbohydrate-containing foods and total dietary carbohydrate, the concept of glycemic load (GL: GI × available carbohydrate content) has also been proposed (Salmeron *et al.*, 1997a, b).

Independent positive association between dietary GI and/or GL and a measure of obesity has been reported in several (Toeller *et al.*, 2001; Ma *et al.*, 2005; Sahyoun *et al.*, 2005; Murakami *et al.*, 2006b), although not all (Amano *et al.*, 2004; Liese *et al.*, 2005), observational studies. In contrast, intake of dietary fiber (unavailable carbohydrate) has been shown to be independently negatively associated with a measure of obesity in several (Appleby *et al.*, 1998; Ludwig *et al.*, 1999; Liu *et al.*, 2003; Sasaki *et al.*, 2003; Spencer *et al.*, 2003; Howarth *et al.*, 2005; Liese *et al.*, 2005), but not all (Stookey, 2001), observational studies. Although high dietary fiber intake is often correlated with low dietary GI and/or GL (Howarth *et al.*, 2001; Bouche *et al.*, 2002; Scholl *et al.*, 2004; Schulze *et al.*, 2004; Sloth *et al.*, 2004; Schulz *et al.*, 2005), few observational studies have examined these dietary factors simultaneously in relation to a measure of obesity, especially in non-Western populations (Toeller *et al.*, 2001; Amano *et al.*, 2004; Sahyoun *et al.*, 2005). Clearly, additional studies are needed on the effects of these dietary factors on the development of obesity. In this cross-sectional study of young Japanese women, we thus examined the associations of total, soluble and insoluble dietary fiber intake and dietary GI and GL with body mass index (BMI) while controlling for a series of potential dietary and nondietary confounders.

Subjects and methods

Subjects and survey procedure

The present study was based on a self-administered questionnaire survey of a wide range of dietary and nondietary behaviors among dietetic students ($n = 4679$) from 54 universities, colleges and technical schools in 33 of 47 prefectures in Japan. A detailed description of the study design and survey procedure is published elsewhere (Murakami *et al.*, 2006a). Briefly, during an orientation session or a first lecture designed for freshman students who entered dietetic courses in April 2005, students answered a dietary assessment questionnaire and another questionnaire on other lifestyle items during the preceding month; in most institutions, this was carried out within 2 weeks after the course began. Responses to the questionnaires were checked at least twice for completeness. When necessary, forms were reviewed with the student to ensure the clarity of answers. Most surveys were completed by May 2005. The protocol of the present study was approved by the Ethics Committee of the National Institute of Health and Nutrition.

In total, 4394 students (4168 women and 226 men) answered both questionnaires (response rate = 93.9%). For the purposes of the current analysis, we selected female subjects aged 18–20 years ($n = 4060$). We then excluded from these 4060 women those who were in an institution where the survey had been conducted at the end of May ($n = 98$), those with extremely low- or high-energy intake (< 2093 or > 16 744 kJ/day) ($n = 23$), and those with missing information on variables used in the present study ($n = 12$). As some subjects were in more than one exclusion category, the final analysis sample comprised 3931 women.

Dietary assessment

Dietary habits during the previous month were assessed using a previously validated, self-administered diet history questionnaire (DHQ) (Sasaki *et al.*, 1998a, b, 2000). This is a 16-page structured questionnaire that consists of the following seven sections: general dietary behavior; major cooking methods; consumption frequency and amount of six alcoholic beverages; consumption frequency and semi-quantitative portion size of 121 selected food and nonalcoholic beverage items; dietary supplements; consumption frequency and amount of 19 staple foods (rice, bread, noodles and other wheat foods) and miso soup (fermented soybean paste soup); and open-ended items for foods consumed regularly (≥ once/week) but not appearing in the DHQ. The food and beverage items and portion sizes in the DHQ were derived primarily from data in the National Nutrition Survey of Japan and several recipe books for Japanese dishes (Sasaki *et al.*, 1998a).

Estimates of dietary intake for 147 food and beverage items, energy, protein, fat, total carbohydrate, alcohol, and total, soluble and insoluble dietary fiber, 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 and data from the open-ended questionnaire items were not used in the calculation of dietary intake. Dietary fiber was determined by an enzymatic–gravimetric procedure (the modified Prosky method) (Science and Technology Agency, 2000) from the intake of 86 fiber-containing foods in the DHQ. Detailed descriptions of the methods used for calculating dietary intake and the validity of the DHQ have been published elsewhere (Sasaki *et al.*, 1998a, b, 2000). The Pearson correlation coefficients between DHQ and 3-day dietary records were 0.48 for energy, 0.48 for protein, 0.55 for fat and 0.48 for total carbohydrate among 47 women (Sasaki *et al.*, 1998a). In addition, the Pearson correlation coefficients between DHQ and 16-day dietary records were 0.79 for alcohol, 0.69 for total dietary fiber, 0.62 for soluble dietary fiber and 0.70 for insoluble dietary fiber among 92 women (Sasaki, unpublished observations, 2004).

The GI of a food is defined as the 2-h incremental area under the blood glucose response curve after consumption of a food portion containing a specific amount, usually 50 g, of available carbohydrate, divided by the corresponding area after consumption of a portion of a reference food, usually glucose or white bread, containing the same amount of available carbohydrate, and multiplied by 100 to be expressed as a percentage (Foster-Powell *et al.*, 2002). We calculated dietary GI by multiplying the percentage contribution of each individual food to daily available carbohydrate intake by the GI value of the food, and then summing these products. Available carbohydrate was calculated as total carbohydrate minus total dietary fiber (Foster-Powell *et al.*, 2002). We also calculated dietary GL by multiplying the dietary GI by the total amount of daily available carbohydrate intake (divided by 100). Although there have been concerns regarding the utility of the GI for mixed meals (overall diet) (Coulston *et al.*, 1987; Hollenbeck and Coulston, 1991), many researchers have shown that the GI of a mixed meal can be predicted consistently as the weighted mean of the GI values of each of the component foods (Wolever and Jenkins, 1986; Chew *et al.*, 1988; Wolever *et al.*, 1991), which was used in the present study.

To determine the GI value of each food for these calculations, each food item on the DHQ was directly matched to foods in the international table of food GI (Foster-Powell *et al.*, 2002), several publications about the GI of Japanese foods (Sugiyama *et al.*, 2003a, b; Hashizume *et al.*, 2004) and a very recent paper about the GI of potatoes (Fernandes *et al.*, 2005). Glucose was used as the reference (GI for glucose = 100). The white bread-based GI values were transformed into glucose-based GI values by multiplying white bread-based GI by 0.7, as in Western studies (Foster-Powell *et al.*, 2002; Fernandes *et al.*, 2005), or by 0.73 (= 100/137 (white bread-based GI value of white bread/white bread-based GI of glucose)) as in Japanese studies (Hashizume *et al.*, 2004). The white rice-based GI values were transformed into glucose-based GI values by multiplying white rice-based GI by 0.82 (= 100/122 (white rice-based GI of white rice/white rice-based GI of glucose)) (Sugiyama *et al.*, 2003a, b). Where more than one GI value was available, GI values were averaged. Ten foods for which a GI value had not been determined were assigned a value corresponding to the nearest comparable food.

Although alcoholic beverages contain little carbohydrate, large quantities of several alcoholic beverages, such as beer and sake, may raise glucose levels slightly. However, GI values of alcoholic beverages have not been established (Ma *et al.*, 2005; Murakami *et al.*, 2006b). Moreover, contribution of available carbohydrate from alcoholic beverages to total available carbohydrate intake was quite low in our population ($0.1 \pm 0.5\%$, mean $\pm$ s.d.). Thus, we ignored alcoholic beverages during the calculation of dietary GI and GL in the present study. Furthermore, foods with a very low available carbohydrate content were excluded because their GI values cannot be tested. The cutoff point for exclusion of foods was set at 3.5 g of available carbohydrate per serving (Ma *et al.*, 2005).

Of the total 147 food and beverage items included in the DHQ, six (4.1%) are alcoholic beverages, eight (5.4%) contain no available carbohydrate and 63 (42.9%) contain <3.5 g of available carbohydrate per serving. The calculation of dietary GI and GL was thus based on the remaining 70 items with GI values ranging from 16 to 91. A detailed description of the calculation of dietary GI and GL used in the present study as well as a table of GI value of each item is published elsewhere (Murakami *et al.*, 2006b). In the present study, the available carbohydrate content of these 70 items contributed to $95.4 \pm 2.2\%$ (mean $\pm$ s.d.) of total available carbohydrate intake, which is comparable with previous studies (Amano *et al.*, 2004 (91%); Ma *et al.*, 2005 (96.2%)).

BMI

Body weight and height were self-reported as part of the DHQ. BMI was calculated as weight (kg) divided by the square of height (m).

Other variables

In a 12-page questionnaire on nondietary lifestyle during the previous month, subjects reported residential area (a place where the subject mainly lived during the previous month). We grouped the reported residential areas into six categories (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; and Kyushu) based on the blocks used in the National Nutrition Survey in Japan (Ministry of Health, Labour, and Welfare, 2004); this variable was herein referred to as 'residential block.' The residential areas were also grouped into three categories according to population size (city with population $\geqslant 1$ million, city with population <1 million, and town and village); this variable was herein referred to as 'size of residential area.' Current smoking (yes or no) and whether currently trying to lose weight (yes or no) were also assessed in the lifestyle questionnaire. Total metabolic equivalent hours (kJ/kg of body weight/day) were computed 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, as described in detail elsewhere (Murakami *et al.*, 2006a). Physical activity level was then calculated by dividing total metabolic equivalent-hours by the standard value of basal metabolic rate for Japanese women aged 18–29 years (99 kJ/kg of body weight/day) (Ministry of Health, Labour, and Welfare, 2005). Rate of eating was self-reported in the DHQ according to one of five qualitative categories (very slow, relatively slow, medium, relatively fast and very fast). In the DHQ, current dietary supplement usage (yes or no) was also asked.

Statistical analysis
All statistical analyses were performed using SAS statistical software, version 8.2. (SAS Institute Inc., Cary, NC, USA). Total, soluble and insoluble dietary fiber intake and dietary GI and GL were examined in relation to BMI. We used energy-adjusted values for dietary fiber intake (g/4186 kJ). We used crude values for dietary GI and energy-adjusted values (/4186 kJ) for dietary GL because, by definition, dietary GI is a measure of carbohydrate quality, not quantity, whereas dietary GL is a measure of combination of carbohydrate quality and quantity. Multivariate adjusted means ± s.e. of BMI were calculated by quintiles of these dietary variables. Confounding variables included in multivariate models were 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), current alcohol drinking (yes or no (because of extremely low alcohol intake: mean = 0.8 g/day)), current dietary supplement usage (yes or no), currently trying to lose weight (yes or no), rate of eating (very slow, relatively slow, medium, relatively fast and very fast), energy intake (quintiles), percentage of energy from protein (quintiles) and percentage of energy from fat (quintiles). For the analyses of total, soluble and insoluble dietary fiber intake, dietary GI or GL was further included in the models. For the analyses of dietary GI and GL, total dietary fiber intake was further included in the models. Linear trends with increasing levels of dietary variables were tested by assigning each participant the median value for the category and modeling this value as a continuous variable. All reported P-values are two-tailed and a P-value of <0.05 was considered statistically significant.

Results

Basic characteristics of the subjects are shown in Table 1. Mean BMI was 21.0 kg/m^2, mean dietary fiber intake 6.5 g/4186 kJ, mean dietary GI 65.1, and mean dietary GL 82.1 (/4186 kJ, crude mean = 147.0). White rice was the major contributor to dietary GI and GL (45.8%), followed by confectioneries (13.7%), bread (10.9%), other rice (5.9%), noodles (5.6%) and sugars (4.8%). Potential confounding variables of the subjects are shown in Table 2 according to quintiles of total dietary fiber intake and dietary GI. Among women in the higher quintiles of total dietary fiber intake, fewer were smokers and more were dietary supplement users, those trying to lose weight and slower eaters. Women in the higher quintiles of total dietary fiber intake also had higher means of physical activity level and energy and protein intake. Mean dietary GI and GL were lower among women in the higher quintiles of total dietary fiber intake. Characteristics of the subjects by quintiles of soluble and insoluble dietary fiber intake showed similar patterns (data not shown). In contrast, among women in the higher quintiles of dietary GI, fewer women were alcohol drinkers, dietary supplement users, those trying to lose weight and slower eaters. Women in the higher quintiles of dietary GI also had lower means of physical activity level and energy, protein and fat intake. Mean total dietary fiber intake was lower among women in the higher quintiles of dietary GI. Characteristics of the subjects by quintiles of dietary GL showed similar patterns (data not shown).

Table 1 Basic characteristics of 3931 Japanese women aged 18–20 years

	Mean ± s.d. or n (%)
Age (years)	18.1 ± 0.3
Body height (cm)	157.9 ± 5.3
Body weight (kg)	52.3 ± 7.7
Body mass index (kg/m^2)	21.0 ± 2.8
Residential block	
Hokkaido and Tohoku	86 (9.8)
Kanto	1351 (34.4)
Hokuriku and Tokai	544 (13.8)
Kinki	780 (19.8)
Chugoku and Shikoku	24 (10.8)
Kyushu	446 (11.4)
Size of residential area	
City with population ⩾1 million	782 (19.9)
City with population <1 million	2550 (64.9)
Town and village	599 (15.2)
Current smoking	
No	3873 (98.5)
Yes	58 (1.5)
Current alcohol drinking	
No	3178 (80.8)
Yes	753 (19.2)
Current dietary supplement usage	
No	3206 (81.6)
Yes	725 (18.4)
Currently trying to lose weight	
No	2511 (63.9)
Yes	1420 (36.1)
Rate of eating	
Very slow	241 (6.1)
Relatively slow	1077 (27.4)
Medium	1149 (29.2)
Relatively fast	1303 (33.2)
Very fast	161 (4.1)
Physical activity level	1.45 ± 0.15
Energy intake (kJ/day)	7627 ± 2110
Protein intake (% of energy)	13.3 ± 2.1
Fat intake (% of energy)	30.0 ± 5.9
Carbohydrate intake (% of energy)	55.2 ± 6.8
Total dietary fiber intake (g/4186 kJ)	6.5 ± 2.0
Soluble dietary fiber intake (g/4186 kJ)	1.7 ± 0.6
Insoluble dietary fiber intake (g/4186 kJ)	4.7 ± 1.5
Dietary glycemic index[a]	65.1 ± 4.3
Dietary glycemic load (/4186 kJ)[a]	82.1 ± 14.6

[a]Glycemic index for glucose = 100.

Table 2 Selected characteristics of 3931 Japanese women aged 18–20 years by quintiles of total dietary fiber intake and dietary glycemic index

	Quintiles of dietary variables					
	1 (n = 786)	*2 (n = 786)*	*3 (n = 787)*	*4 (n = 786)*	*5 (n = 786)*	P[a]
Total dietary fiber intake (g/4186 kJ)	4.2±0.6[b]	5.3±0.2	6.1±0.2	7.1±0.3	9.5±2.0	
Current smokers (%)	3.3	1.3	1.4	0.4	1.0	<0.0001
Current alcohol drinkers (%)	20	20	18	20	18	0.44
Current dietary supplement users (%)	13	16	17	22	25	<0.0001
Subjects currently trying to lose weight (%)	29	34	35	38	44	<0.0001
Rate of eating (%)						<0.0001
Very slow	7	5	5	5	9	
Relatively slow	24	25	27	31	31	
Medium	33	30	29	26	28	
Relatively fast	33	36	35	33	30	
Very fast	5	4	4	5	3	
Physical activity level	1.43±0.14	1.44±0.14	1.44±0.16	1.47±0.17	1.47±0.16	<0.0001
Energy intake (kJ/day)	7351±2051	7690±2206	7606±1984	7845±2131	7644±2152	0.008
Protein intake (% of energy)	12.1±2.0	12.8±1.9	13.1±1.8	13.6±1.9	14.7±2.2	<0.0001
Fat intake (% of energy)	29.6±7.1	30.5±5.9	30.1±5.5	30.5±5.5	29.3±5.4	0.11
Dietary glycemic index[c]	67.5±4.0	66.0±3.5	65.2±3.8	64.3±3.8	62.4±4.5	<0.0001
Dietary glycemic load (/4186 kJ)[c]	89.3±17.1	84.0±13.5	82.7±12.8	79.2±12.6	75.4±12.9	<0.0001
Dietary glycemic index[c]	58.8±2.6	63.1±0.8	65.4±0.6	67.5±0.7	70.7±1.6	
Current smokers (%)	1.8	1.8	0.8	1.9	1.2	0.40
Current alcohol drinkers (%)	22	22	20	16	15	<0.0001
Current dietary supplement users (%)	26	19	18	17	13	<0.0001
Subjects currently trying to lose weight (%)	44	38	36	32	31	<0.0001
Rate of eating (%)						0.01
Very slow	9	6	5	5	6	
Relatively slow	30	28	27	28	25	
Medium	26	29	29	32	32	
Relatively fast	31	33	36	32	34	
Very fast	5	4	3	4	4	
Physical activity level	1.46±0.17	1.46±0.16	1.45±0.15	1.44±0.15	1.43±0.14	0.0002
Energy intake (kJ/day)	8221±2486	7949±2122	7769±2001	7409±1842	6786±1733	<0.0001
Protein intake (% of energy)	14.2±2.3	13.5±2.1	13.3±2.0	13.1±1.9	12.2±1.8	<0.0001
Fat intake (% of energy)	32.1±5.9	31.2±5.5	30.6±5.3	29.7±5.5	26.5±5.8	<0.0001
Total dietary fiber intake (g/4186 kJ)	7.7±2.5	6.9±1.9	6.3±1.7	6.0±1.6	5.4±1.6	<0.0001

[a]For continuous variables, tests for linear trend used the median value in each quintile as a continuous variable in linear regression; a Mantel–Haenszel χ^2 test was used for categorical variables.
[b]Data are mean±s.d., unless otherwise indicated.
[c]Glycemic index for glucose = 100.

Adjusted means of BMI across quintiles of total, soluble and insoluble dietary fiber intake and dietary GI and GL are shown in Table 3. After adjustment for potential dietary and nondietary confounding variables (model 1), total dietary fiber intake was significantly negatively correlated with BMI (mean difference between the lowest and highest quintiles = −0.6 kg/m^2; P for trend <0.0001). The negative correlation between total dietary fiber intake and BMI was still significant after further controlling for dietary GI (model 2: mean difference = −0.4 kg/m^2; P for trend = 0.0007) or GL (model 3: mean difference = −0.4 kg/m^2; P for trend = 0.006). A similar negative correlation with BMI was also observed for both soluble dietary fiber intake (model 2: mean difference = −0.6 kg/m^2; P for trend < 0.0001, and model 3: mean difference = −0.6 kg/m^2; P for trend = 0.0004) and insoluble dietary fiber intake (model 2: mean difference = −0.5 kg/m^2; P for trend = 0.001 and model 3: mean difference = −0.4 kg/m^2; P for trend = 0.008). In contrast, both dietary GI and GL were significantly positively correlated with BMI after controlling for confounding variables (model 1: mean difference = 0.5 kg/m^2; P for trend = 0.0003 and mean difference = 1.2 kg/m^2; P for trend <0.0001, respectively). This positive correlation with BMI was still significant after further adjustment for total dietary fiber intake (model 4) for both dietary GI (mean difference = 0.4 kg/m^2; P for trend = 0.03) and GL (mean difference = 1.0 kg/m^2; P for trend = 0.0005).

We further examined the joint association of total dietary fiber intake and dietary GI or GL with BMI by cross-classifying subjects by using tertiles of these dietary variables

Table 3 Body mass index according to quintiles of total, soluble, and insoluble dietary fiber intake and dietary glycemic index and load among 3931 Japanese women aged 18–20 years[a,b]

	Quintiles of dietary variables					
	1 (n = *786*)	*2* (n = *786*)	*3* (n = *787*)	*4* (n = *786*)	*5* (n = *786*)	P *for trend*[c]
Total dietary fiber intake (g/4186 kJ)	4.3	5.3	6.1	7.1	9.0	
Body mass index (kg/m²)						
Model 1[d]	21.2±0.1	21.1±0.1	21.1±0.1	20.8±0.1	20.6±0.1	<0.0001
Model 2[e]	21.1±0.1	21.0±0.1	21.1±0.1	20.8±0.1	20.7±0.1	0.0007
Model 3[f]	21.1±0.1	21.0±0.1	21.1±0.1	20.8±0.1	20.7±0.1	0.006
Soluble dietary fiber intake (g/4186 kJ)	1.1	1.4	1.6	1.9	2.4	
Body mass index (kg/m²)						
Model 1[d]	21.3±0.1	21.1±0.1	21.0±0.1	20.9±0.1	20.5±0.1	<0.0001
Model 2[e]	21.2±0.1	21.1±0.1	21.0±0.1	20.9±0.1	20.6±0.1	<0.0001
Model 3[f]	21.2±0.1	21.1±0.1	21.0±0.1	20.9±0.1	20.6±0.1	0.0004
Insoluble dietary fiber intake (g/4186 kJ)	3.2	3.9	4.4	5.1	6.5	
Body mass index (kg/m²)						
Model 1[d]	21.2±0.1	21.0±0.1	21.1±0.1	20.9±0.1	20.6±0.1	<0.0001
Model 2[e]	21.1±0.1	21.0±0.1	21.1±0.1	20.9±0.1	20.6±0.1	0.001
Model 3[f]	21.1±0.1	21.0±0.1	21.1±0.1	20.9±0.1	20.7±0.1	0.008
Dietary glycemic index[g]	59.5	63.1	65.4	67.5	70.4	
Body mass index (kg/m²)						
Model 1[d]	20.7±0.1	20.8±0.1	21.0±0.1	21.0±0.1	21.2±0.1	0.0003
Model 4[h]	20.8±0.1	20.9±0.1	21.0±0.1	21.0±0.1	21.2±0.1	0.03
Dietary glycemic load (/4186 kJ)[g]	64.3	73.9	81.5	89.2	101.1	
Body mass index (kg/m²)						
Model 1[d]	20.4±0.1	20.6±0.1	20.9±0.1	21.3±0.1	21.6±0.2	<0.0001
Model 4[h]	20.5±0.2	20.7±0.1	20.9±0.1	21.2±0.1	21.5±0.2	0.0005

[a]Values are expressed as median for dietary variables and as mean±s.e. for body mass index.
[b]Cutoffs of quintile categories of dietary variables were 4.9, 5.7, 6.6 and 7.7 g/4186 kJ for total dietary fiber intake; 1.2, 1.5, 1.7 and 2.1 g/4186 kJ for soluble dietary fiber intake; 3.6, 4.2, 4.8 and 5.7 g/4186 kJ for insoluble dietary fiber intake; 61.6, 64.4, 66.4, and 68.7 for dietary glycemic index; and 69.9, 78.1, 85.0 and 93.8/4186 kJ for dietary glycemic load.
[c]Linear trends were tested with increasing levels of dietary variables by assigning each participant the median value for the category and modeling this variable as a continuous variable.
[d]Adjusted for 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), current alcohol drinking (yes or no), current dietary supplement usage (yes or no), currently trying to lose weight (yes or no), rate of eating (very slow, relatively slow, medium, relatively fast, or very fast), physical activity level (quintiles), energy intake (quintiles), percentage of energy from protein (quintiles) and percentage of energy from fat (quintiles).
[e]Model 1 with additional adjustment for dietary glycemic index (quintiles).
[f]Model 1 with additional adjustment for dietary glycemic load (quintiles).
[g]Glycemic index for glucose = 100.
[h]Model 1 with additional adjustment for total dietary fiber intake (quintiles).

(Figure 1). Adjusted mean BMI for the combination of a high total dietary fiber intake (third tertile) and a low dietary GI (first tertile) (20.5 kg/m^2) was significantly lower than that for the combination of a low total dietary fiber intake (first tertile) and a high dietary GI (third tertile) (21.3 kg/m^2, $P = 0.003$ (Dunnett's test)) and that for the combination of a medium total dietary fiber intake (second tertile) and a high dietary GI (21.2 kg/m^2, $P = 0.03$) (Figure 1a). Similarly, the adjusted mean value of BMI for the combination of a high total dietary fiber intake and a low dietary GL (20.3 kg/m^2) was significantly lower than that for the combination of a low total dietary fiber intake and a high dietary GL (21.6 kg/m^2, $P = 0.04$) (Figure 1b).

Discussion

To the best of our knowledge, this study is the first to examine dietary fiber intake and dietary GI and GL simultaneously in relation to BMI, while controlling for a wide range of potential confounders, among a relatively large sample of young women ($n = 3931$). We found that dietary fiber intake was independently negatively correlated with BMI, and dietary GI and GL were independently positively correlated with BMI.

Total dietary fiber intake showed an independent negative correlation with BMI (Table 3). A similar inverse relation between total dietary fiber intake and BMI has been reported

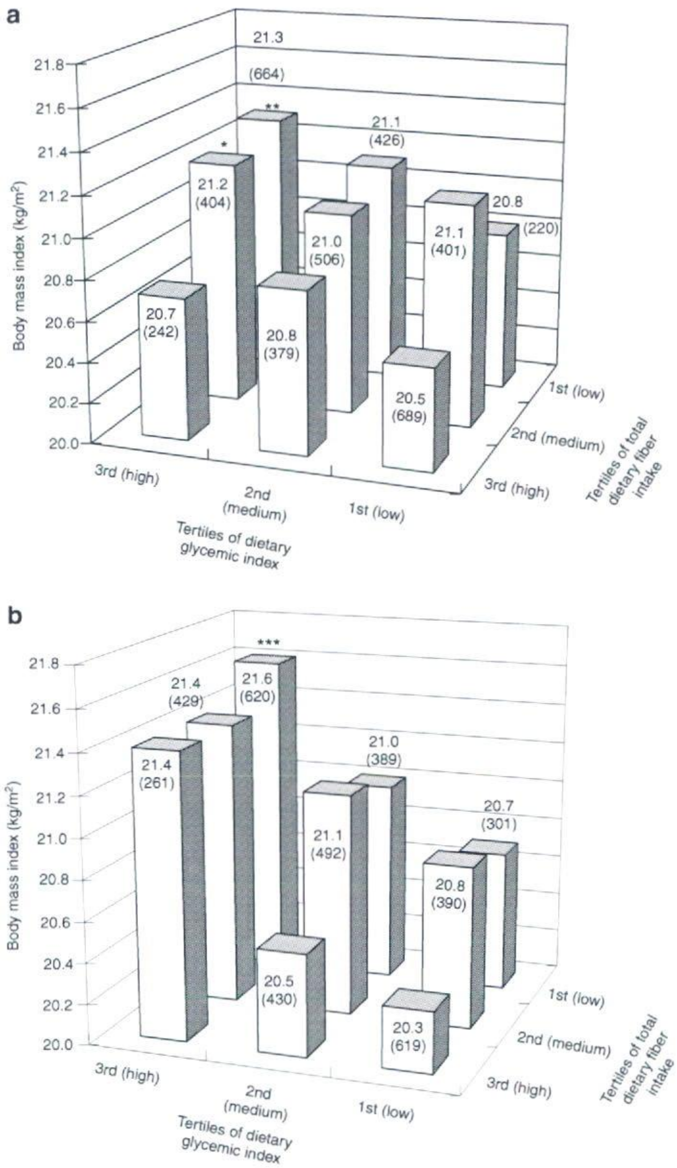

Figure 1 Body mass index by different levels of total dietary fiber intake and dietary glycemic index (GI) (**a**) or glycemic load (GL) (**b**) among the 3931 Japanese women aged 18–20 years. Dietary variables were stratified by tertiles (first (low): <5.5 g/4186 kJ; second (medium): 5.5–6.9 g/4186 kJ; and third (high): >6.9 g/4186 kJ for total dietary fiber intake, first (low): <63.5; second (medium): 63.5–67.1; and third (high): >67.1 for dietary GI, and first (low): <75.4/4186 kJ; second (medium): 75.4–87.6/4186 kJ; and third (high): >87.6/4186 kJ for dietary GL (GI for glucose = 100)). Values are expressed as means adjusted for residential block (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; and Kyushu), size of residential area (city with population $\geqslant 1$ million, city with population <1 million, and town and village), current smoking (yes or no), current alcohol drinking (yes or no), current dietary supplement usage (yes or no), currently trying to lose weight (yes or no), rate of eating (very slow, relatively slow, medium, relatively fast or very fast), physical activity level (quintiles), energy intake (quintiles), percentage of energy from protein (quintiles) and percentage of energy from fat (quintiles). The number of subjects in each combination is shown in parentheses. Significance level compared with the category of high total dietary fiber intake and low dietary GI or load by Dunnett's test: *$P = 0.03$, **$P = 0.003$ and ***$P = 0.04$.

in previous cross-sectional studies (Appleby *et al.*, 1998; Sasaki *et al.*, 2003; Spencer *et al.*, 2003; Howarth *et al.*, 2005; Liese *et al.*, 2005), although one study did not show an inverse association (Stookey, 2001). Higher total dietary fiber intake has also been associated with lower body weight gain (Ludwig *et al.*, 1999) and lower increase in body weight and BMI (Liu *et al.*, 2003) in several prospective studies. Additionally, two recent reviews of trials of high versus low total dietary fiber intake have shown that the majority of studies support a beneficial effect of total dietary fiber against weight gain (Howarth *et al.*, 2001; Pereira and Ludwig, 2001).

Despite differences in physiological effects between soluble and insoluble dietary fiber, the beneficial effects on weight control have been suggested regarding both soluble and insoluble dietary fiber (Howarth *et al.*, 2001). Few epidemiologic studies have compared different dietary fiber types and their association with a measure of obesity. In the present study, both soluble and insoluble dietary fiber intakes were negatively correlated with BMI, although the magnitude seemed to be somewhat larger in soluble than in insoluble dietary fiber intake (Table 3).

Both dietary GI and GL showed an independent positive correlation with BMI (Table 3). Several *ad libitum* trials conducted on nondiabetic subjects have suggested a beneficial effect of low-GI diet on fat mass (Bouche *et al.*, 2002) and body weight (Bouche *et al.*, 2002; Sloth *et al.*, 2004), when compared with high-GI diet, although other trials conducted on subjects with type II diabetes have found no differences in body weight change between high- and low-GI diets (Heilbronn *et al.*, 2002; Jimenez-Cruz *et al.*, 2003; Rizkalla *et al.*, 2004). Additionally, although there has been no association between dietary GI and GL and BMI in some studies (Amano *et al.*, 2004; Liese *et al.*, 2005), other observational studies have shown a positive association between dietary GI, but not dietary GL and BMI (Ma *et al.*, 2005; Murakami *et al.*, 2006b).

Our dietary GI and GL values (65 and 147), consistent with those in a previous Japanese study (64 and 150) (Amano *et al.*, 2004), were higher when compared with those in Western countries (49–58 and 81–145) (Salmeron *et al.*, 1997a, b; Toeller *et al.*, 2001; Heilbronn *et al.*, 2002; Jimenez-Cruz *et al.*, 2003; Rizkalla *et al.*, 2004; Scholl *et al.*, 2004; Schulze *et al.*, 2004, 2005; Ma *et al.*, 2005; Sahyoun *et al.*, 2005). This may primarily result from the differences in the major food contributors, whereas dietary GI and GL in Western populations were determined by a variety of foods (potatoes (7–8%), breakfast cereals (4–7%), bread (5%) and rice (5%)) (Liu *et al.*, 2000, 2002; Jonas *et al.*, 2003), the contribution of white rice (GI = 77) was dominant in the present study (46%).

Higher total dietary fiber intake was strongly correlated with lower dietary GI or GL (Table 2). Considering that both the negative correlation between total dietary fiber intake and BMI and the positive correlation between dietary GI or GL and BMI observed in the analyses with adjustment for a variety of confounding factors (model 1 in Table 3) slightly attenuated after further adjustment for each other (models 2–4 in Table 3), both the association of total dietary fiber intake with BMI and the association of dietary GI and GL with BMI may have two pathways, that is, a direct one and an indirect one through each other (dietary fiber, and dietary GI or GL). Supporting this hypothesis, the combination diet high in total dietary fiber and low in dietary GI or GL was more strongly correlated with low BMI (Figure 1) than either one alone (models 2–4 in Table 3).

All self-reported dietary assessment methods are subject to measurement error and selective underestimation and/or overestimation of dietary intake (Livingstone and Black, 2003). Our DHQ, although similar to most previous epidemiologic studies, was not designed specifically to measure dietary GI and GL. To minimize data inaccuracy, however, we used a previously validated DHQ (Sasaki *et al.*, 1998a, b, 2000); regarding dietary GI and GL, the satisfactory validity of our DHQ for total carbohydrate (Sasaki *et al.*, 1998a) and total dietary fiber (Sasaki, unpublished observations, 2004) provides some reassurance. Additionally, the same tendency of correlations between dietary variables and BMI was observed in a repeated analysis of 2792 subjects with a 'physiologically plausible' energy intake (subjects possessing a ratio of reported energy intake to estimated basal metabolic rate (standard value of basal metabolic rate for Japanese women aged 18–29 years (99 kJ/kg of body weight/day) multiplied by body weight of each subjects (kg)) (Ministry of Health, Labour, and Welfare, 2005) of 1.2–2.5 (Black *et al.*, 1996)) (data not shown). Thus, although the effect of measurement error and selective underestimation and/or overestimation of dietary intake can never be excluded, it is not likely that inaccuracy of dietary data may have a major impact on the findings in the present study.

We used BMI values calculated from self-reported body weight and height, which might be biased. Previous studies have shown that BMI calculated from self-reported body weight and height is highly correlated with BMI calculated from measured values (Goodman *et al.*, 2000; Kuczmarski *et al.*, 2001). It is thus suggested that BMI calculated from self-reported body weight and height is a reliable measure at least for use in correlation analysis.

Because this was a cross-sectional study, there was a possibility that subjects with higher BMI altered their diets. We included current attempts to lose weight in multivariate models as a covariate to take into account this possible confounding. Additionally, further adjustment for intentional dietary change within 1 year, assessed as part of the DHQ, did not change the results materially (data not shown). Moreover, as mentioned above, the repeated analysis of 'physiologically plausible' energy reporters, where a considerable number of subjects with current dieting to lose weight, if any, should be excluded, provided similar results. It is therefore less likely that the present results are strongly influenced by possible alternation of diets in subjects with higher BMI.

Our results may not be extrapolated to general Japanese populations because the subjects selected were female dietetic students who may be highly health conscious. To minimize the influence of nutritional education, the present survey was carried out, in most institutions, within 2 weeks after the dietetic course began. Although we attempted to adjust for a wide range of potential confounding variables, we cannot rule out residual confounding owing to these or poorly measured variables, such as physical activity level assessed by a limited number of nonvalidated questions, as well as other unknown variables.

To conclude, after adjustment for a variety of potential dietary and nondietary confounding factors, dietary fiber intake was negatively correlated with BMI, and dietary GI and GL were positively correlated with BMI in this study of 3931 relatively lean Japanese women aged 18–20 years. Because the cross-sectional nature of the present study precludes any causal inferences, however, further research using prospective designs is required to clarify these relationships.

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