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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

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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

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,

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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

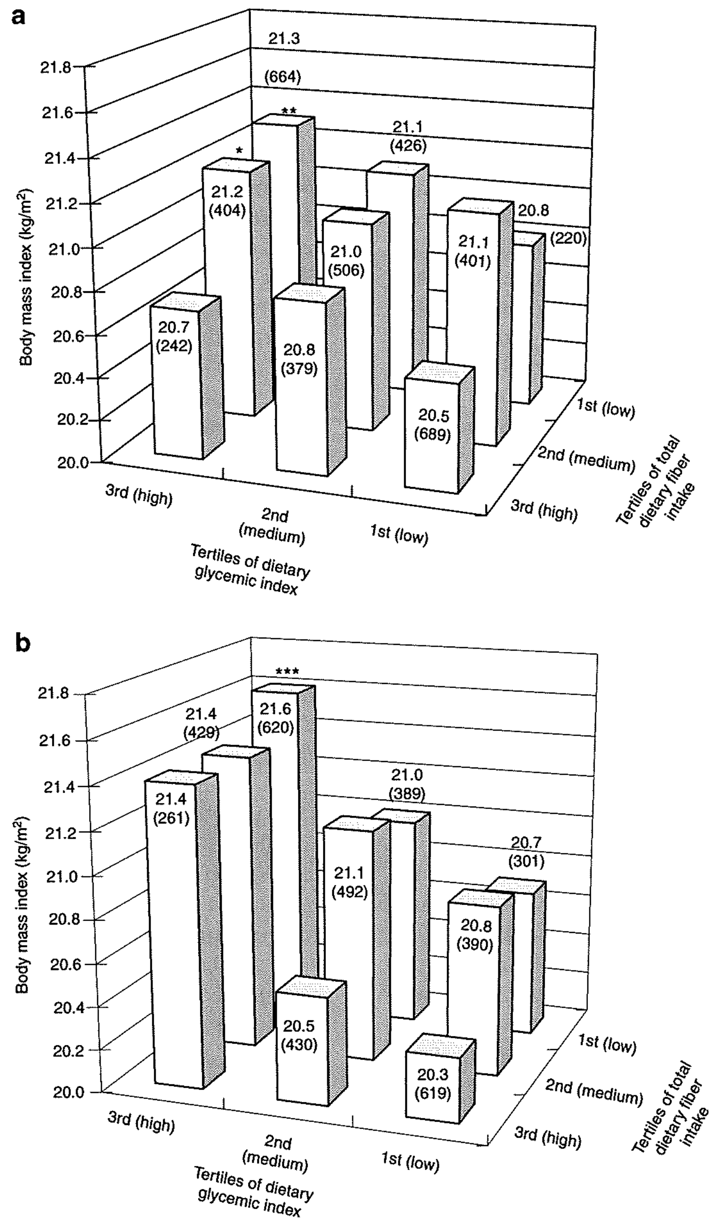

Figure 1 Body mass index by different levels of total dietary fiber intake and dietary glycemic index (GI) (**a**) or glycemic load (GL) (**b**) among the 3931 Japanese women aged 18–20 years. Dietary variables were stratified by tertiles (first (low): <5.5 g/4186 kJ; second (medium): 5.5–6.9 g/4186 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 ⩾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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Hardness (difficulty of chewing) of the habitual diet in relation to body mass index and waist circumference in free-living Japanese women aged 18–22 y[1–3]

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ABSTRACT

Background: Animal studies suggest the beneficial effect of hardness of diet on body weight and adiposity. No human studies have examined hardness of diet in relation to obesity.

Objective: We examined cross-sectional associations of hardness of the habitual diet with body mass index (BMI; in kg/m^2) and waist circumference in free-living humans.

Design: Subjects were 454 female Japanese dietetic students aged 18–22 y. Dietary hardness was assessed as an estimate of masticatory muscle activity for the habitual diet (ie, the difficulty of chewing the food). The consumption of a total of 107 foods was estimated by means of a self-administered, comprehensive diet history questionnaire, and masticatory muscle activity during the ingestion of these foods was estimated according to published equations. Waist circumference was measured at the level of the umbilicus.

Results: Mean BMI was 21.4 (95% CI: 21.1, 21.6), and mean waist circumference was 73.6 (72.9, 74.3) cm. Mean dietary hardness was 178 (175, 181) mV · s/1000 kcal. Dietary hardness was not significantly associated with BMI. However, it was negatively associated with waist circumference (*P* for trend = 0.005). This association remained after adjustment not only for potential confounding factors (*P* for trend = 0.028) but also for BMI (*P* for trend = 0.002).

Conclusions: Whereas no association between dietary hardness and BMI was seen, increasing dietary hardness was associated with lower waist circumference even after adjustment for BMI in free-living young Japanese women. This finding could make innovative contributions to the literature and raise issues for future studies regarding diet and obesity. *Am J Clin Nutr* 2007;86:206–13.

KEY WORDS Hardness of diet, body mass index, waist circumference, Japanese, women, diet history questionnaire, epidemiology

INTRODUCTION

Because the human genome has hardly changed since the emergence of behaviorally modern humans ≈10 000 y ago, contemporary humans are still genetically adapted for the foods consumed by our remote ancestors (1–5). The dietary choices of that time would necessarily have been limited to minimally processed or unprocessed—and, often, uncooked—wild plant and animal foods (2). In contrast, the contemporary diet in affluent societies mainly consists of foods that could not have been regularly consumed before the development of agriculture, industrialization, and advanced technology such as food-processing procedures; these foods include dairy products, cereals, refined cereals, refined sugars, refined vegetable oils, fatty meats, salt, and combinations of these foods (3). The collision of our ancient genome with the new conditions of life in affluent nations, including the dietary qualities of recently introduced foods is considered to be the ultimate factor underlying diseases of civilization, including obesity (3–5). Given that probability, the differences between the ancient dietary patterns and those currently prevalent in industrialized countries appear to have important implications for the prevention and treatment of contemporary chronic diseases, including obesity. A dietary characteristic that would differ greatly between the ancient dietary patterns and the contemporary dietary patterns in developed societies is hardness of the diet, referred to hereafter as dietary hardness.

However, no human studies have examined with diligence the possible association between dietary hardness and diseases of civilization, such as obesity. In contrast, several studies in mice

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(6, 7) and rats (8, 9) suggested the beneficial effect of dietary hardness on obesity. In this preliminary study, we tried to examine hardness of the habitual diet in relation to body mass index (BMI; in kg/m^2) and waist circumference (WC; in cm) among young free-living Japanese women. For this examination, we assessed dietary hardness by using an estimate of masticatory muscle activity for the habitual diet, obtained with data on the consumption of a total of 107 foods estimated by a self-administered comprehensive diet history questionnaire (DHQ) (10–12) and data on masticatory muscle activities during the ingestion of these foods estimated according to published equations (13).

SUBJECTS AND METHODS

Subjects

The present study was based on a multicenter nutritional survey conducted in February and March 2006 among female dietetics students from 10 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. Subjects who responded positively were then provided detailed written and oral explanations of the general purpose and procedure of the survey. A total of 474 women took part. For the present analysis, we selected 454 women who met the following 3 inclusion criteria: they were 18–22 y old (n = 467); were not currently receiving dietary counseling from a doctor or dietitian (n = 468); and had a reported energy intake in the range of 1000–3500 kcal/d (n = 467).

Written informed consent was obtained from each subject, and also from a parent for subjects aged <20 y. The study protocol was approved by the Ethics Committee of the Japanese National Institute of Health and Nutrition (of Japan).

Dietary assessment

Dietary habits during the preceding month were assessed by using a self-administered comprehensive DHQ (10–12). Responses to the DHQ, as well as those 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 16-page structured questionnaire that consists of 7 sections: general dietary behavior; major cooking methods; consumption frequency and amount of 6 alcoholic beverages; consumption frequency and semiquantitative portion size of 118 selected food and nonalcoholic 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 (≥1 time/wk) but not appearing in the DHQ (10). 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 books of recipes for Japanese dishes (10). Estimates of dietary intake for a total of 150 food and beverage items (including 5 seasonings), energy, and nutrients were calculated by using an ad hoc computer algorithm for the DHQ based on the Standard Tables of Food Composition in Japan (14). Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation of dietary intake (10). Detailed descriptions of the methods used to calculate dietary intake and the validity of the DHQ with respect to nutrients have been published elsewhere (10–12). Pearson's correlation coefficients between the DHQ and 3-d estimated dietary records were 0.48 for energy and 0.48–0.55 for macronutrients in 47 women (10). In addition, Pearson's correlation coefficient between the DHQ and 16-d weighed dietary records was 0.71 for dietary fiber in 92 women, and the mean value of Spearman's correlation coefficients of food groups was 0.44 (range: 0.13–0.77; S Sasaki, unpublished observations, 2006).

Estimation of dietary hardness

In the present study, dietary hardness was assessed as estimated masticatory muscle activity needed for the habitual diet (ie, the difficulty of chewing the food in the diet). Whereas the habitual diet was assessed by DHQ (10–12) as described above, estimates of masticatory muscle activity for each food in the DHQ were obtained from equations published by Yanagisawa et al (13). Those authors measured the activities of 6 muscle regions (mV · s) involved in mastication (right and left masseters and anterior and posterior temporalis) by using electromyography during the ingestion of the same volume (1.3 × 1.3 × 1.3 cm) of 16 selected foods with various physical properties by 20 healthy Japanese adults (10 men and 10 women) with a mean age of 21 y. They found that masticatory muscle activities (mV · s/2.197 cm^3) were highly correlated with the physical properties of foods (ie, firmness, cohesiveness, and strain) as measured with a texturometer (GTX-2; Zenken KK Inc, Chiba, Japan) and developed the following equations (13):

$$\text{Masticatory muscle activity} = 0.6586 \times \ln(\text{firmness} \times \text{cohesiveness} \times \text{strain} \times 10) - 0.0307 \quad (1)$$

where $R^2 = 0.89$;

$$\text{Masticatory muscle activity} = 0.2718 \times \text{firmness} + 0.0335 \times \text{strain} - 0.0030 \quad (2)$$

where $R^2 = 0.89$; or

$$\text{Masticatory muscle activity} = 0.3081 \times \text{firmness} + 0.3300 \quad (3)$$

where $R^2 = 0.81$.

Using the information on the physical properties of foods they had measured earlier with a texturometer (15), Yanagisawa et al (13) then estimated masticatory muscle activities for a total of 144 foods according to one of their equations, by using the available variables (ie, firmness, cohesiveness, and strain).

They did not, however, cross-validate the equations to show their applicability (13). We therefore conducted a cross-evaluation by using data reported by Shiono et al (16). Those authors measured the activities of 4 muscle regions (mV · s) involved in mastication (right and left masseters and anterior temporalis, but not posterior temporalis) by using electromyography during the ingestion of standard-sized bites (2.4–44.5 g) of 46 selected foods with various physical properties by 6 healthy Japanese adults (3 men and 3 women) aged 23–27 y. By careful direct matching, information on masticatory muscle activities for a total of 18 foods was available from Shiono et al (16) and information on physical properties was available from Yanagisawa et al (15). Pearson's correlation coefficient between masticatory muscle activities measured by Shiono et al (mV · s/g food) (16) and those estimated by using physical property values as described by Yanagisawa et al [mV · s/g food (= mV · s/2.197 cm^3 divided by 2.197, assuming that the density of all foods = 1)] (13) was 0.88 among these 18 foods. This high correlation suggests the applicability of the equations developed by Yanagisawa et al, despite the differences in masticatory muscles measured and in the amounts of foods consumed in the studies of Yanagisawa et al (13) and Shiono et al (16).

We directly matched each food item on the DHQ (n = 150) (10–12) with foods for which information on masticatory muscle activities was available (n = 144) from Yanagisawa et al (13). During the calculation of dietary hardness, we excluded from the 150 food items on the DHQ beverages (22 items), soups (4 items), seasonings including fat and oil (16 items), and water (1 item). Foods for which masticatory muscle activities had not been determined (21 items) were assigned a value according to that of a comparable food. Because the physical properties (and hence the hardness, or difficulty of chewing) of vegetables are greatly influenced by cooking with heat (13), we took those influences into account as much as possible. For tomatoes and cucumbers, we used values for raw tomatoes and raw cucumbers, respectively, because these vegetables are usually consumed without heating in Japan. For cabbage, we used a weighted mean of a value for raw cabbage and that for boiled leafy vegetables (because of a lack of information on boiled cabbage), based on the ratio of the observed consumption (g/d) of raw cabbage to that of cabbage cooked with heat (ie, 4:6) in 92 women (S Sasaki, unpublished observations, 2006). For carrots, we used a weighted mean of a value for raw carrots and that for boiled carrots, based on the ratio of the observed consumption (g/d) of raw carrots to that of carrots cooked with heat (ie, 3:7) in 92 women (S Sasaki, unpublished observations, 2006). For other vegetables, we used values adjusted for cooking with heat, given that these foods are usually consumed after cooking with heat in Japan. Dietary hardness was calculated as the sum of the products of estimated masticatory activities (mV · s/2.197 cm^3) and the volume of food consumed (cm^3/d) divided by 2.197. For the estimation of food volume, we simply converted weight in grams to weight in cubic centimeters for all of the foods, on the assumption that the density of all foods = 1. Because the crude value of dietary hardness was strongly correlated with energy intake (Pearson's correlation coefficient = 0.75), the energy-adjusted value (mV · s/1000 kcal) was used in the present study. Estimates of masticatory muscle activity for the 107 food items used to calculate dietary hardness are presented in **Table 1**. We could not investigate the validity of the DHQ against the 16-d dietary records (which we used to investigate the validity of other dietary variables, as described above) in assessing dietary hardness, because an insufficient number of foods (n = 144 items) with information on hardness (ie, masticatory muscle activity) (13) prevented the calculation of dietary hardness by the 16-d dietary records.

Anthropometric measurements

Body height was measured to the nearest 0.1 cm while the subjects were standing and not wearing shoes. Body weight was measured to the nearest 0.1 kg while the subjects were wearing lightweight indoor clothing. WC was measured to the nearest 0.1 cm at the level of the umbilicus. The measurement was taken at the end of a normal respiration while the subjects were standing erect and with the arms at the side and the feet together.

Other variables

In the lifestyle questionnaire, the subject reported her residential area, which was grouped into 1 of 3 regions: northern (Kanto and Tohoku), central (Tokai, Hokuriku, and Kinki), or southern (Kyushu and Chugoku) Japan. The residential areas were also grouped into 3 categories according to population size (city with population ≥ 1 million, city with population < 1 million, or town or village). Current smoking status (yes or no) and whether the subject was currently trying to lose weight (yes or no) were self-reported in the lifestyle questionnaire. Physical activity was computed as the average metabolic equivalent-hours [MET · h/d (17)], on the basis of the frequency and duration of 5 different activities (sleeping, high- and moderate-intensity activities, walking, and sedentary activities) over the preceding month as reported in the lifestyle questionnaire. Rate of eating (slow, medium, or fast) was self-reported as part of the DHQ.

Statistical analysis

All statistical analyses were performed with SAS software (version 8.2: SAS Institute Inc, Cary, NC). With the use of the PROC GLM procedure, linear regression models were constructed to examine the association of dietary hardness with BMI and WC. For analyses, subjects were categorized into quintiles according to dietary hardness values (mV · s/1000 kcal). Mean (± SE) values of BMI and WC were calculated by quintiles of dietary hardness with or without adjustment for potential confounding factors, including residential area, size of residential area, current smoking, currently trying to lose weight, physical activity (total MET · h/d, continuous), rate of eating, and energy intake (kcal/d, continuous). In the analysis of WC, BMI (continuous) was also included as a confounding variable. We also conducted analyses with further adjustment for nutrient intakes, including protein (% of energy, continuous), fat (% of energy, continuous), and dietary fiber (g/1000 kcal, continuous). Because alcohol intake was extremely low ($\bar{x}$: 1.4 g/d), alcohol intake was not considered a confounding factor. We tested for linear trends with increasing levels of dietary hardness by assigning each participant the median value for the category and modeling this value as a continuous variable. All reported P values are 2-tailed, and $P < 0.05$ was considered significant.

RESULTS

Basic characteristics of the subjects are shown in **Table 2**. Mean BMI was 21.4 (95% CI: 21.1, 21.6), and mean WC was 73.6 (72.9, 74.3) cm. Mean dietary hardness was 178 (175, 181) mV · s/1000 kcal (range: 101–289 mV · s/1000 kcal). The top contributor to dietary hardness was well-milled rice (27.0%), and next were spaghetti (4.1%), pork (3.9%), green leafy vegetables (3.7%), and cabbage (3.4%), as shown in Table 1. Potential confounding factors are shown by quintile of dietary hardness in **Table 3**. There was a negative association between dietary hardness and rate of eating. Dietary hardness was negatively associated with energy and fat intakes and positively associated with protein and dietary fiber intakes.

TABLE 1

Hardness of the 107 food items used in the present study[1]

Food item	Hardness	Contribution to dietary hardness[2]
	mV · s/1000 kcal	*%*
Well-milled rice	225	27.04 ± 15.22[3]
Spaghetti	339	4.07 ± 3.78
Pork	236	3.87 ± 2.97
Green leafy vegetables	1701	3.65 ± 3.32
Cabbage	2546	3.44 ± 3.04
Chicken	351	2.85 ± 2.37
Eggs	135	2.41 ± 1.50
Beef	345	2.37 ± 2.39
Japanese noodles (buckwheat and Japanese wheat noodles)	278	2.37 ± 2.19
Chinese cabbage	2404	1.84 ± 2.10
Mushrooms	2560	1.80 ± 1.66
Instant noodles	236	1.74 ± 2.48
White bread	76	1.60 ± 1.60
Apples	664	1.49 ± 2.19
Carrots	857	1.45 ± 1.07
Brown rice	230	1.41 ± 5.91
Well-milled rice with germ	227	1.33 ± 6.26
Wakame seaweed	3265	1.32 ± 1.50
Salted pickles (excluding plums)	2652	1.21 ± 2.15
Chinese noodles	236	1.19 ± 2.13
Japanese bread with a sweet filling	70	1.16 ± 1.46
Ground beef and pork	198	1.12 ± 0.98
Broccoli[4]	1360	1.11 ± 1.38
Pizza	209	1.11 ± 1.97
Lettuce	3971	1.05 ± 1.21
Onions	555	0.97 ± 0.75
Natto (fermented soybeans)	129	0.94 ± 1.11
Oily fish	143	0.92 ± 0.82
Cucumbers	3327	0.82 ± 1.15
Shrimp	711	0.79 ± 0.68
Squid and octopus	691	0.79 ± 0.87
Well-milled rice mixed with barley	259	0.77 ± 4.91
White meat fish	229	0.76 ± 0.65
Bean sprouts	2892	0.74 ± 0.86
Oranges	212	0.74 ± 1.18
Red meat fish	225	0.73 ± 0.65
Dried fish	265	0.70 ± 1.12
Green peppers	2417	0.65 ± 0.91
70%-Milled rice	225	0.63 ± 4.64
Cornflakes[4]	170	0.60 ± 1.66
Tofu (soybean curd) products	266	0.59 ± 0.98
French fries	218	0.59 ± 0.80
Cheese	91	0.58 ± 0.90
Sweet potatoes, yams, and taro	175	0.52 ± 0.55
Japanese-style pancakes[4]	112	0.50 ± 0.73
Small fish with bones	766	0.47 ± 0.66
Butter roll	80	0.46 ± 1.00
Bananas	165	0.45 ± 0.80
Ground fish meat products	327	0.42 ± 0.64
Cakes	50	0.41 ± 0.46
Burdock	578	0.40 ± 0.61
Croissant	46	0.38 ± 0.76
Tomatoes	568	0.38 ± 0.42
Potatoes	101	0.37 ± 0.38
Rice crackers	112	0.36 ± 0.56
Ham and sausages	97	0.36 ± 0.39
Radishes	450	0.35 ± 0.30
Sweetened yogurt[4]	78	0.32 ± 0.58
Konnyaku (devil's tongue jelly)	6309	0.32 ± 0.53
Japanese sweets with azuki beans	138	0.31 ± 0.43
Half-milled rice	227	0.30 ± 2.70
Tofu	74	0.30 ± 0.26
Shellfish other than oysters	1042	0.29 ± 0.41
Doughnuts	51	0.28 ± 0.46
Cookies and biscuits	36	0.26 ± 0.36
Eggplants	1337	0.26 ± 0.39
Strawberries	317	0.24 ± 0.28
Bacon	86	0.24 ± 0.34
Pancakes[4]	72	0.23 ± 0.57
Canned tuna	101	0.22 ± 0.31
Snacks made from wheat flour	57	0.21 ± 0.33
Boiled beans	75	0.21 ± 0.35
Liver	468	0.19 ± 0.40
Nonsweetened yogurt[4]	85	0.17 ± 0.54
Nutritional supplement bars[4]	131	0.16 ± 0.61
Chocolates[4]	9	0.16 ± 0.22
Moderately sweetened yogurt[4]	81	0.15 ± 0.46
Salted pickled plums[4]	626	0.15 ± 0.25
Raisins	199	0.14 ± 0.38
Oysters	885	0.14 ± 0.25
Ice cream (unspecified varieties)[4]	24	0.13 ± 0.20
Pumpkins	75	0.13 ± 0.15
Japanese sweets without azuki beans	145	0.12 ± 0.22
Ice cream (regular)[4]	23	0.11 ± 0.31
Nuts (not peanuts)	95	0.11 ± 0.18
Cauliflower[4]	1413	0.11 ± 0.45
Peanuts	78	0.11 ± 0.29
Boiled fish, shellfish, and seaweed in soy sauce	246	0.10 ± 0.27
Potato chips	42	0.09 ± 0.15
Jellies	73	0.08 ± 0.14
Kiwi fruit[4]	171	0.07 ± 0.18
Candies, caramels, and chewing gum[4]	13	0.07 ± 0.11
Lotus root[4]	183	0.07 ± 0.15
Canned fruits	146	0.05 ± 0.09
Persimmons	504	0.04 ± 0.18
Cottage cheese	293	0.04 ± 0.12
Pears	704	0.03 ± 0.23
Eel	41	0.02 ± 0.05
Laver (dried, edible seaweed)[4]	196	0.02 ± 0.02
Fish eggs[4]	25	0.02 ± 0.03
Salted fish intestines	467	0.02 ± 0.05
Jam and marmalade[4]	10	0.02 ± 0.04
Ice cream (premium)[4]	25	0.01 ± 0.10
Peaches	279	0.01 ± 0.07
Melons	126	0.00 ± 0.02
Grapes[4]	39	0.00 ± 0.01
Watermelons	201	0.00 ± 0.02

[1] These 107 food items from the 150 items in the diet history questionnaire were used for the calculation of dietary hardness. The remaining 43 items not used consisted of 22 beverages [fruit juice (100%), other fruit juice, tomato juice, vegetable juice, beer, sake, shochu, shochu mixed with water or a carbonated beverage, whiskey, wine, green and oolong tea, black tea, coffee, cocoa, lactic acid bacteria beverages, sugar-sweetened soft drinks, sugar-free soft drinks, nutritional supplement drinks, full-fat milk, low-fat milk, skim milk, and cream or creamer added to coffee], 4 soups (corn soup, Chinese soup, soup consumed with noodles, and water for miso soup), 16 seasonings including fat and oil (sugar for coffee and black tea, sugar used during cooking, butter, margarine, mayonnaise, salad dressing, fat-free salad dressing, oil used during cooking, miso as seasoning, miso for miso soup, ketchup, table salt, salt used during cooking, soy sauce, curry and roux in stew, and artificial sweeteners), and drinking water. Food items are listed in the descending order of their mean contribution to overall dietary hardness.

[2] Based on the data for subjects in the present study (454 Japanese women aged 18–22 y).

[3] $\bar{x}$ ± SD (all such values).

[4] These 21 food items were assigned the hardness value of a comparable food.

TABLE 2
Basic characteristics of 454 Japanese women aged 18–22 y

	Value
Age (y)	19.6 ± 1.0[1]
Body height (cm)	158.1 ± 5.5
Body weight (kg)	53.4 ± 8.1
BMI (kg/m^2)	21.4 ± 3.0
Waist circumference (cm)	73.6 ± 7.4
Area of residence [*n* (%)]	
North (Kanto and Tohoku)	267 (59)
Central (Tokai, Hokuriku, and Kinki)	85 (19)
South (Kyushu and Chugoku)	102 (22)
Size of residential area [*n* (%)]	
City with a population ≥1 million	80 (18)
City with a population <1 million	334 (74)
Town or village	40 (9)
Current smoking [*n* (%)]	
No	441 (97)
Yes	13 (3)
Currently trying to lose weight [*n* (%)]	
No	342 (75)
Yes	112 (25)
Physical activity (total metabolic equivalents · h/d)	34.1 ± 3.5
Rate of eating [*n* (%)]	
Slow	140 (31)
Medium	144 (32)
Fast	170 (37)
Energy intake (kcal/d)	1761 ± 406
Protein intake (% of energy)	13.9 ± 1.9
Fat intake (% of energy)	29.5 ± 5.0
Carbohydrate intake (% of energy)	55.1 ± 5.8
Dietary fiber intake (g/1000 kcal)	7.1 ± 2.1
Dietary hardness (mV · s/1000 kcal)	178 ± 31

[1] $\bar{x}$ ± SD (all such values).

Mean values of BMI and WC across quintiles of dietary hardness are shown in **Table 4**. Dietary hardness was not significantly associated with BMI, regardless of adjustment for potential confounding factors. Conversely, dietary hardness was significantly and negatively associated with WC (in model 1, the mean difference in WC between the lowest and highest quintiles of dietary hardness was −2.9 cm; *P* for trend = 0.005). The significant negative association between dietary hardness and WC remained after adjustment for potential confounding factors (in model 2, mean difference: −2.7 cm; *P* for trend = 0.028) and also BMI (in model 4, mean difference: −2.4 cm; *P* for trend = 0.002). This inverse association seemed mainly due to the composition of the diet, because it disappeared after further adjustment for dietary intake (models 3 and 5).

DISCUSSION

To our knowledge, this is the first study to examine dietary hardness in relation to BMI and WC in humans. We found that, whereas there was no association with BMI, dietary hardness was negatively associated with WC even after adjustment for BMI in free-living young Japanese women. No human studies have examined the association between dietary hardness and obesity, but several animal studies have suggested the beneficial effect of a hard diet on obesity. Mice fed a hard diet from age 4 wk had a significantly lower body weight at age 36 wk than did mice fed a normal diet (6). In addition, body-weight gain from 4 to 9 wk of age was significantly smaller in male (but not female) mice fed a hard diet than in those fed a soft diet (7), and body-weight gain at age 6 wk was significantly smaller in rats fed a hard diet from age 1 wk than in those fed a soft diet (8). Furthermore, rats fed a hard diet from age 4–26 wk had significantly lower body weight and abdominal white adipose tissue than did those fed a soft diet (9).

TABLE 3
Selected characteristics of 454 Japanese women aged 18–22 y according to quintile (Q) of dietary hardness

	Q1 (*n* = 90)	Q2 (*n* = 91)	Q3 (*n* = 91)	Q4 (*n* = 91)	Q5 (*n* = 91)	*P*[1]
Dietary hardness (mV · s/1000 kcal)	137 ± 13[2]	161 ± 5	176 ± 5	193 ± 6	223 ± 19	
Area of residence (%)						< 0.0001
North (Kanto and Tohoku)	72	68	57	54	43	
Central (Tokai, Hokuriku, and Kinki)	17	20	14	15	27	
South (Kyushu and Chugoku)	11	12	29	31	30	
Size of residential area (%)						0.10
City with a population ≥1 million	18	16	19	24	11	
City with a population <1 million	79	78	68	66	77	
Town or village	3	5	13	10	12	
Current smokers (%)	1	7	3	0	3	0.68
Subjects currently trying to lose weight (%)	26	29	21	29	20	0.42
Physical activity (total metabolic equivalents · h/d)	34.7 ± 5.2	33.8 ± 2.7	33.6 ± 2.4	34.1 ± 3.0	34.1 ± 3.3	0.51
Rate of eating (%)						0.03
Slow	32	23	27	37	34	
Medium	27	31	32	32	37	
Fast	41	46	41	31	29	
Energy intake (kcal/d)	1885 ± 419	1770 ± 410	1782 ± 375	1665 ± 394	1704 ± 403	0.0006
Protein intake (% of energy)	13.1 ± 1.6	13.4 ± 1.7	13.8 ± 1.6	14.1 ± 1.9	15.0 ± 1.9	< 0.0001
Fat intake (% of energy)	31.0 ± 4.5	30.3 ± 5.6	29.8 ± 4.9	27.7 ± 5.0	28.6 ± 4.6	< 0.0001
Dietary fiber intake (g/1000 kcal)	6.0 ± 1.2	6.3 ± 1.2	6.6 ± 1.5	7.1 ± 1.8	9.5 ± 2.4	< 0.0001

[1] For continuous variables, a linear trend test was used with the median value in each quintile as a continuous variable in linear regression; a Mantel-Haenszel chi-square test was used for categorical variables.
[2] $\bar{x}$ ± SD (all such values).

TABLE 4
BMI and waist circumference according to quintile (Q) of dietary hardness in 454 Japanese women aged 18–22 y

	Q1 (n = 90)	Q2 (n = 91)	Q3 (n = 91)	Q4 (n = 91)	Q5 (n = 91)	P for trend[1]
Dietary hardness (mV · s/1000 kcal)	142 (101–152)[2]	163 (153–167)	176 (168–183)	192 (184–204)	216 (205–289)	
BMI (kg/m^2)						
Model 1[3]	21.4 ± 0.3[4]	21.6 ± 0.3	21.3 ± 0.3	21.4 ± 0.3	21.1 ± 0.3	0.47
Model 2[5]	21.3 ± 0.3	21.5 ± 0.3	21.3 ± 0.3	21.4 ± 0.3	21.2 ± 0.3	0.73
Model 3[6]	21.1 ± 0.3	21.4 ± 0.3	21.2 ± 0.3	21.3 ± 0.3	21.7 ± 0.4	0.38
Waist circumference (cm)						
Model 1	75.0 ± 0.8	74.4 ± 0.8	73.0 ± 0.8	73.8 ± 0.8	71.9 ± 0.8	0.005
Model 2	74.9 ± 0.8	74.0 ± 0.8	73.1 ± 0.8	73.9 ± 0.8	72.2 ± 0.8	0.028
Model 3	74.3 ± 0.8	73.7 ± 0.8	72.9 ± 0.8	73.7 ± 0.8	73.6 ± 0.9	0.63
Model 4[7]	74.9 ± 0.5	73.7 ± 0.5	73.1 ± 0.5	73.8 ± 0.5	72.5 ± 0.5	0.002
Model 5[8]	74.8 ± 0.5	73.6 ± 0.5	73.1 ± 0.5	73.8 ± 0.5	72.9 ± 0.6	0.063

[1] A linear trend test was used with the median value in each quintile as a continuous variable in linear regression.
[2] Median; range in parentheses (all such values).
[3] Crude model.
[4] $\bar{x}$ ± SE (all such values).
[5] Adjusted for residential area (Kanto and Tohoku in the north; Tokai, Hokuriku, and Kinki in the central area; or Kyushu and Chugoku in the south), size of residential area (city with a population ≥1 million, city with a population <1 million, or town or village), current smoking (yes or no), currently trying to lose weight (yes or no), physical activity (total metabolic equivalents · h/d, continuous), rate of eating (slow, medium, or fast), and energy intake (kcal/d, continuous).
[6] Adjusted for variables used in model 2, protein and fat intake (% of energy, continuous), and dietary fiber intake (g/1000 kcal, continuous).
[7] Adjusted for variables used in model 2 and BMI (in kg/m^2, continuous).
[8] Adjusted for variables used in model 3 and BMI (in kg/m^2, continuous).

We do not know why we found unexpected null association with BMI (but found the expected inverse association with WC). Several limitations of the present study, such as the narrow range of BMIs in the subjects, the study's cross-sectional design, and the use of a new and as yet unestablished method for assessing dietary hardness, may at least partly explain the null finding on BMI. Alternatively, the difference in abdominal white adipose tissue was much larger (22%) than that in body weight (6%) between rats fed a soft and those fed a hard diet (9), which may suggest that dietary hardness affects abdominal obesity (eg, WC) more strongly than it affects overall obesity (eg, BMI).

The negative association between dietary hardness and WC was independent of energy intake. Less body weight gain with a hard diet was related to decreased food intake in a study of rats (8). Conversely, the effect of dietary hardness on obesity was independent of the amount of foods consumed in other studies of mice (6) and rats (9), which may be due to increased thermogenesis (9) or unknown mechanisms. However, the negative association between dietary hardness and WC was not independent of diet composition, because that association disappeared after control for dietary composition. This finding is not consistent with findings from animal studies, because dietary hardness had a beneficial effect on obesity independent of diet composition (6–9). However, the question of whether the association of dietary hardness with obesity is independent of dietary composition should be examined and interpreted with caution, because, whereas dietary hardness can freely be changed in animal models while dietary composition remains constant, dietary hardness is associated with dietary composition in the diet of free-living humans. In the present study, greater dietary hardness was associated with healthier dietary patterns, including lower energy and fat and higher protein and dietary fiber. Several human studies have supported the favorable effects of healthy dietary patterns, including a high intake of dietary fiber (18–21) and a low intake of dietary fat (18, 19), on WC, which does not conflict with our finding.

Several limitations of the present study should be acknowledged. First, our subjects were selected female dietetics students, not a random sample of Japanese women, and the exact response rate was unknown because of our recruitment procedure: these elements of the design may produce recruitment bias. Thus, it may be that our results cannot be extrapolated to the general Japanese population.

Second, because this was a cross-sectional study, reverse causation may have occurred. However, it is unlikely that subjects with a large WC would intentionally change the hardness of their diet as a result of an increase in WC, because the notion that dietary hardness is associated with a measure of obesity is not well known. Furthermore, adjustment for intentional dietary change within the preceding year (yes or no), assessed as part of the DHQ, did not materially change the present results (data not shown). It is therefore reasonable to consider that our findings are not due to reverse causation.

Third, our DHQ was not designed specifically to measure dietary hardness, and the validity of the DHQ with respect to dietary hardness was unknown. The satisfactory validity of the DHQ for a wide range of nutrients and foods (10–12; S Sasaki, unpublished observations, 2006), however, may provide some reassurance. In addition, the DHQ may not adjust sufficiently for cooking methods in the calculation of dietary hardness. Our mean estimate of dietary hardness [crude $\bar{x}$ (±SD): 312 ± 82 mV · s/d; range: 140–647 mV · s/d] was higher than that assessed by 3-d dietary records in a group of 140 women aged 18–23 y (267 ± 69 mV · s/d; 109–523 mV · s/d) (22), although the estimation of dietary hardness by using dietary records would be less reliable because the database of hardness (ie, masticatory muscle activity) is limited to a few food items (13). Moreover, we simply converted weight in grams to weight in cubic centimeters for all foods, assuming that the density of all foods = 1, even though for some foods that are high in air content (eg, snack foods), weight and volume are not directly proportional (23). Nevertheless, foods making the greatest contribution to dietary hardness in the present study did not seem to have this disproportional relation between weight and volume (*see* Table 1). Because the procedure we used provides only an approximation of the actual hardness of habitual diet, the results of the present study should be interpreted with great caution. Nevertheless, our findings should provide valuable insights into this poorly explored research issue.

Furthermore, misreporting of food intake, particularly by overweight persons, is a serious problem in self-reported dietary assessment methods (24). Consistent misreporting across all types of foods likely has little influence on energy-adjusted dietary hardness values (25), but studies indicate that overweight persons may selectively underreport their intakes of fatty or sugary foods (26, 27), which could cause dietary hardness estimations to be higher than actual values. In the present study, the potential shared error created by underreporting of dietary measures by subjects with a high BMI (and WC) would likely have weakened the associations of dietary hardness with measures of obesity and could possibly have led to a null finding; this possibility may at least partly explain the lack of association with BMI. Nonetheless, we did find a significant negative association with WC.

Finally, although we attempted to adjust for a wide range of potential confounding variables, we could not rule out residual confounding. Physical activity in particular was assessed relatively roughly from only 5 different activities, a number that may not have been sufficient. In addition, whereas dental status has an influence on food and nutrient intakes and on obesity (28–30), particularly in older persons, we unfortunately had no information on the subjects' dental status, which could confound the present results for young women. Although impaired dental status may be less pervasive in young than in elderly populations, and although the percentage of subjects in a similar population (3828 Japanese female dietetics students aged 18–20 y) who had been diagnosed by a dentist as having a dental disease was relatively small (8%) (S Sasaki, unpublished observations, 2007), further research on dietary hardness and health should take the subjects' dental status into account.

In conclusion, the results of the present study showed that, whereas there was no association between dietary hardness and BMI, dietary hardness was a significant independent determinant of WC in a group of free-living young Japanese women. Because these observations are generally consistent with the results of several animal studies (6–9), the present findings could make innovative contributions to the literature and raise issues for future studies on diet and obesity. However, because this is a preliminary study with a novel, as yet unestablished method of assessing dietary hardness, the results should be interpreted with great caution; nevertheless, applications of the method of assessing dietary hardness to other similar datasets would be of some interest. To better understand the influence of dietary hardness on obesity, further observational and intervention studies are clearly needed. To conduct such investigations, it is urgent to develop a database of values for a variable indicating hardness (eg, masticatory muscle activity) of various food items.

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The author's responsibilities were as follows—KMurakami: contributed to the concept and design of the study, the study protocol, data management, and coordinated the field work, calculated the dietary hardness, analyzed and interpreted the data, and wrote the manuscript; SS: the concept and design of the study, the study protocol, and data management, and contributed to the writing and editing of the manuscript; YT: the writing and editing of the manuscript; KU: the concept and design of the study, the study protocol, and data collection; MY, HH, TG, JO, KB, KO, TK, KMuramatsu, and MF: data collection. All authors contributed to the preparation of the manuscript and approved the final version submitted for publication. None of the authors had any personal or financial conflict of interest.

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Nutrient and food intake in relation to serum leptin concentration among young Japanese women

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Abstract

Objective: Little is known about the relation of modifiable dietary factors to circulating leptin concentrations, particularly in young adults and non-Western populations. We examined cross-sectional associations between nutrient and food intake and serum leptin concentration in young Japanese women.
Methods: Subjects were 424 female Japanese dietetic students 18–22 y of age. Intake of macronutrients (protein, total fat; saturated, monounsaturated, and polyunsaturated fatty acids; and carbohydrate), dietary fiber, and 12 food groups was assessed with a validated, self-administered, comprehensive, diet history questionnaire. Fasting blood samples were collected, and serum leptin concentrations were measured by radioimmunoassay.
Results: For nutrients, only dietary fiber was a significant determinant of serum leptin concentration. Increasing dietary fiber intake was associated with lower serum leptin concentration independent of potential confounding factors, including body mass index (mean serum leptin concentrations in the lowest and highest quintiles of dietary fiber intake were 8.6 and 7.5 ng/mL, respectively; P for trend = 0.026). Vegetables and pulses were the only foods significantly associated with serum leptin concentration, with higher intakes independently associated with lower concentrations (mean serum leptin concentrations in the lowest and highest quintiles of intake were 8.1 and 7.0 ng/mL, P for trend = 0.007, for vegetables and 8.8 and 7.6 ng/mL, P for trend = 0.019, for pulses, respectively).
Conclusion: Intake of dietary fiber, vegetables, and pulses showed an independent inverse association with serum leptin concentration in a group of young Japanese women.

Keywords: Dietary fiber; Vegetables; Pulses; Leptin; Japanese women; Epidemiology.

Introduction

Circulating leptin concentrations are highly positively correlated with body mass index (BMI) [1]. Despite this strong association, levels show large individual variation for a given level of adiposity [1], indicating the likely affect of variables other than adipose mass, such as genetic and environmental factors. Given the potential for positive associations of leptin concentration with subsequent weight gain [2] and the development of cardiovascular disease [3,4], the identification of modifiable lifestyle factors asso-

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ciated with leptin levels, e.g., dietary habits, is vitally important from a prevention perspective [5].

Relatively little is known about the effect of specific dietary factors on circulating serum levels [6]. Although several Western studies have failed to find significant associations between energy-providing nutrient intake and circulating leptin concentrations [7,8], total fat and polyunsaturated fatty acid intakes were significantly positively associated with plasma leptin level in middle-aged American men [9]. At the food level, a favorable effect of whole grains [10], vegetables [11], and fish [12] has been suggested in Western studies. However, evidence from people in non-Western countries and young adult populations is limited [7–12]. We conducted a cross-sectional study of associations between nutrient and food intake and serum leptin concentration in a group of young Japanese women.

Materials and methods

The present study was based on a multicenter survey conducted from February to March 2006 among female dietetic students from 10 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 responding positively were then provided detailed written and oral explanations of the general purpose and procedure of the survey. A total of 474 women took part. 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 from a parent for subjects <20 years old. For the present analysis, we selected 424 women who met the following five inclusion criteria: age 18–22 y (n = 467), not currently receiving dietary counseling from a doctor or a dietitian (n = 468), having a reported energy intake within 1000–3500 kcal/d (n = 467), able to provide a fasting blood sample (n = 465), and having measured serum leptin concentrations (n = 452).

Dietary habits during the preceding month were assessed using a previously validated, self-administered, comprehensive, diet history questionnaire (DHQ) [13–15]. 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. Estimates of dietary intake for a total of 150 food and beverage items, energy, and selected nutrients were calculated using an ad hoc computer algorithm for the DHQ based on the Standard Tables of Food Composition in Japan [16]. Pearson's correlation coefficients between the DHQ and 3-d estimated dietary records were 0.48 for protein, 0.55 for total fat, 0.75 for saturated fatty acid, 0.50 for monounsaturated fatty acid, 0.37 for polyunsaturated fatty acid, and 0.48 for carbohydrate in 47 women [13]. In addition, Pearson's correlation coefficients between the DHQ and 16-d semiweighed dietary records were 0.48 for protein, 0.60 for total fat, 0.71 for saturated fatty acid, 0.55 for monounsaturated fatty acid, 0.34 for polyunsaturated fatty acid, 0.64 for carbohydrate, and 0.70 for dietary fiber in 92 women, and the mean value of Spearman's correlation coefficients of food groups was 0.44, with a range of 0.13 to 0.77 (unpublished observations, S. Sasaki, 2006).

About 1–3 d after completion of the questionnaires, blood was sampled after an overnight fast in evacuated tubes containing no additives, allowed to clot, and centrifuged at 3000g for 10 min at room temperature to separate serum. According to the survey protocol, blood samples were transported at −20°C by car or airplane to ensure delivery to a laboratory in Tokyo (SRL Inc., Tokyo, Japan) within 2 d of collection to avoid significant degradation. Serum leptin concentrations were measured at SRL by radioimmunoassay. In-house quality-control procedures were fulfilled at SRL. The within- and between-assay coefficients of variation were 3.5% and 4.2%, respectively.

Body height was measured to the nearest 0.1 cm with the subject standing without shoes. Body weight in light indoor clothing was measured to the nearest 0.1 kg. BMI was calculated as body weight (kilograms) divided by the square of body height (meters). In the lifestyle questionnaire, the subject reported her residential area, which was grouped into one of three regions (north: Kanto and Tohoku, central: Tokai and Hokuriku, or south: Kyushu and Chugoku) and into three categories according to population size (city with population ≥1 million, city with population <1 million, or town and village). Current smoking status (yes or no) was self-reported in the lifestyle questionnaire. Rate of eating (slow, medium, or fast) was self-reported as part of the DHQ. Alcohol drinking was assessed using the DHQ and grouped into three categories (non-drinker, >0% to <1% energy, or ≥1% energy). Physical activity was computed as average metabolic equivalent-hours [17] 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 reported in the lifestyle questionnaire.

Associations with serum leptin concentration were examined for the intake of selected nutrients including protein, total fat, saturated, monounsaturated, and polyunsaturated fatty acids, carbohydrate, and dietary fiber and 12 food groups (cereals, potatoes, confectioneries, fats and oils, fruits, vegetables including mushrooms and seaweeds, pulses including nuts, meats, eggs, fish and shellfish, dairy products, and beverages). We used energy-adjusted values of dietary intake, i.e., percentage of energy from protein, fat including fatty acids, and carbohydrate and amounts (grams) per 1000 kcal of energy for dietary fiber and foods. For analyses, subjects were categorized into quintiles according to dietary intake. Mean values (95% confidence intervals) for serum leptin concentration were calculated after multivariate adjustment for potential confounding fac-