ELSEVIER

Nutrition 22 (2006) 490–495

NUTRITION

www.elsevier.com/locate/nut

Applied nutritional investigation

No relation between intakes of calcium and dairy products and body mass index in Japanese women aged 18 to 20 y

Kentaro Murakami, M.Sc.[a], Hitomi Okubo, R.D., M.Sc.[b], and Satoshi Sasaki, M.D., Ph.D.[a,*]

[a] *National Institute of Health and Nutrition, Tokyo, Japan*
[b] *Kagawa Nutrition University, Saitama, Japan*

Manuscript received May 12, 2005; accepted December 14, 2005.

Abstract

Objective: This cross-sectional study examined possible associations of intakes of calcium and dairy products to body mass index (BMI; kilograms per square meter) in young Japanese women.
Methods: Subjects were 1905 female Japanese dietetic students who were 18 to 20 y of age. Dietary intake was assessed over a 1-mo period with a validated, self-administered diet history questionnaire. BMI was computed by using self-reported weight and height. BMI among quartiles of energy-adjusted intakes (per 1000 kcal) of calcium and dairy products was compared while controlling for intakes of protein, fat, and dietary fiber, self-reported rate of eating, and other non-dietary variables.
Results: Mean BMI ± standard deviation was 20.8 ± 2.6 kg/m^2. Mean estimated intakes were 268 ± 93 mg/1000 kcal for calcium and 80 ± 63 g/1000 kcal for dairy products. Intakes of calcium and dairy products were not significantly associated with BMI (adjusted means in the lowest and highest quartiles were 20.7 and 20.8 for calcium, P for trend = 0.48, and 20.6 and 20.6 for dairy products, P for trend = 0.81). These results were also observed after excluding 481 energy under- and over-reporters for calcium (20.4 and 20.5, respectively, P for trend = 0.73) and dairy products (20.3 and 20.4, respectively, P for trend = 0.73).
Conclusions: Intakes of calcium and dairy products may not necessarily be associated with BMI among young Japanese women who not only are relatively lean but also have a relatively low intake of calcium and dairy products.

Keywords: Calcium intake; Dairy product intake; Body mass index; Japanese women; Epidemiology

Introduction

A recently emerging body of literature suggests that the intake of calcium and/or dairy products may protect humans against the development of obesity [1–15]. A possible theory is that a low calcium intake causes high intracellular calcium concentrations, which in turn promote lipogenesis, inhibit lipolysis, and decrease thermogenesis, whereas a high calcium intake reverses these trends [3]. It seems that the effect of calcium in the form of dairy products may be greater than that of elemental calcium [16]. However, several published reports have not supported the potentially favorable effects of calcium and/or dairy products on measurements of obesity [17–22]. Thus, the relation of calcium and/or dairy product intake to obesity remains unclear. In addition, research on this issue has been conducted mainly in Western countries, whereas information is quite limited in non-Western countries including Japan, where the prevalence of obesity and dietary intakes of calcium and dairy products are relatively low [23]. Therefore, we investigated possible associations of intakes of calcium and dairy products with body mass index (BMI) in young Japanese women.

Materials and methods

Subjects were students who entered dietetic courses at 22 colleges and technical schools in three of the four main islands of Japan in April 1997 (n = 2069) [24–26].

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

0899-9007/06/$ – see front matter
doi:10.1016/j.nut.2005.12.003

A total of 2063 students (2017 women and 46 men) participated in the survey (response rate 99.7%). For statistical analysis, we selected female subjects who were 18 to 20 y of age ($n = 1960$). We excluded from the 1960 women those who were currently receiving dietary counseling ($n = 33$), those with an extremely low or high reported energy intake (<775 or >3950 kcal/d, $n = 18$), and those with missing information on variables used in the present study ($n = 6$). Because some subjects were in more than one exclusion category, the final analytic sample contained 1905 subjects.

Dietary habits during the previous month were assessed by using a previously validated, self-administered diet history questionnaire (DHQ) [27–29]. Measurements of dietary intake for 147 food and beverage items, energy, protein, fat, carbohydrate, alcohol, dietary fiber, and calcium were calculated by using an ad hoc computer algorithm developed for the DHQ, which was based on the *Standard Tables of Food Composition in Japan* [30]. Although dietary supplement usage was queried in the DHQ, intake from dietary supplements was not included in this study due to the lack of a reliable composition table of dietary supplements in Japan. Dairy products consisted of full-fat, low-fat, and skimmed milk, sweetened and non-sweetened yogurt, cheese, cottage cheese, ice cream, and coffee cream [31]. Pearson's correlation coefficient between DHQ and 3-d diet records was 0.49 for calcium intake that was adjusted for energy intake by using a residual model among 47 women [27]. For dairy products (grams per 1000 kcal), Spearman's correlation coefficient between DHQ and 16-d diet records was 0.52 among 92 women (unpublished observations, S. Sasaki, 2004).

Body weight and height were self-reported as part of the DHQ. BMI was computed as weight (kilograms) divided by the square of height (meters). In the DHQ, subjects also reported their rate of eating (very slow, relatively slow, medium, relatively fast, or very fast) and intentional dietary change (no, changed within 1 y, changed within 3 y, or changed >3 y ago). In addition, a self-administered questionnaire on general lifestyle during the previous month asked about the following four variables: current smoking (yes or no), experience of dieting (≥2 kg intentional decrease in body weight within 1 mo, yes or no), residential area, and participation in sports club activities (times per month) without inquiring into the types of sports, intensity, or duration. Residential areas were categorized into 12 regional blocks according to the *National Nutrition Survey in Japan* [23]. Because relatively few subjects were categorized into three of these blocks (Hokkaido, Tohoku, and Hokuriku), they were included in their adjacent blocks, resulting in nine categories (Kanto II, Hokkaido, and Tohoku; Kanto I; Tokai and Hokuriku; Kinki I; Kinki II; Chugoku; Shikoku; Kita-kyushu; and Minami-kyushu). The residential areas were also divided into three categories according to population (city with population ≥1 million, city with population <1 million, or town and village). Subjects who participated in sports club activities at least once per week were regarded as "active" and all others as "sedentary" without consideration of other kinds of activities.

All statistical analyses were performed with SAS 8.2 (SAS Institute, Cary, NC, USA). For analyses, subjects were categorized into quartiles according to the energy-adjusted intakes (per 1000 kcal) of calcium and dairy products. Mean BMI ± standard error (SE) was calculated by quartiles of these variables while controlling for a series of covariates that could affect body weight (residential block [nine categories], size of residential area [three categories], current smoking [two categories], alcohol drinking [yes or no because of extremely low alcohol intake, mean 0.8 g/d], physical activity [two categories], experience of dieting [two categories], intentional dietary change [four categories], rate of eating [five categories], protein intake [percentage of energy intake, continuous], fat intake [percentage of energy intake, continuous], and dietary fiber intake [grams per 1000 kcal, continuous]). We did not include percentage of energy intake from carbohydrate as a covariate because of its very high correlation with percentage of energy intake from fat (Pearson's correlation coefficient −0.94). We tested for linear trends with increasing levels of intakes of calcium and dairy products by assigning each participant the median value for the category and modeling this value as a continuous variable. We also calculated the partial regression coefficient (β) and SE for intakes of calcium and dairy products by multiple regression analysis with BMI as the dependent variable, with adjustment for the potential confounding variables indicated above. All reported P values are two-tailed, and $P < 0.05$ was considered statistically significant.

In a previous study [7], the size of the effect of calcium intake on BMI was -0.26 kg/m^2 per 100 mg per 1000-kcal increase in calcium intake. In our population [24], mean calcium intake ± standard deviation was 306 ± 148 mg/1000 kcal, and the standard deviation of BMI was 2.6 kg/m^2. Using these values, power calculations revealed that a sample of 532 women (133 women in each quartile category) was sufficient to demonstrate the expected difference (-0.89 kg/m^2) between the highest and lowest quartile categories (excepted medians 477 and 136 mg/1000 kcal, respectively), with 80% power at the $\alpha = 0.05$ significance level. Because these calculations for t test (not for analysis of variance or test for linear trend) did not take into consideration the adjustment for potential confounding variables, a larger number of subjects was needed in practice. However, our sample ($n = 1905$) was much larger than the calculated sample size, indicating that its size was sufficient for detecting the difference in BMI between extreme quartiles, if the size of the effect of calcium on BMI similar to that observed in the previous study [7] was really present in our population.

Results

Basic characteristics of the subjects are presented in Table 1. Mean BMI ± standard deviation of subjects was 20.8 ± 2.6 kg/m^2, and mean intakes were 268 ± 93 mg/1000 kcal for calcium and 80 ± 63 g/1000 kcal for dairy products. Potential confounding variables of the subjects are listed in Table 2 according to quartiles of intakes of calcium and dairy products. Among women in the higher quartiles of those intakes, more were defined as physically active and reported recent intentional dietary changes. Women in the higher quartiles of those intakes also had higher means of protein, fat, and dietary fiber intake. There were more subjects with dieting experience and more slower eaters in the higher quartiles of calcium intake.

As presented in Table 3, after adjustment for potential confounding variables, calcium and dairy product intakes were not significantly associated with BMI (adjusted means in the lowest and highest quartiles were 20.7 and 20.8 kg/m^2 for calcium, P for trend = 0.48, and 20.6 and 20.6 kg/m^2 for dairy products, P for trend = 0.81). Similar insignificant associations were observed when calcium and dairy products were treated as continuous variables in multiple regression analyses ($\beta \pm$ SE −0.0002 ± 0.0008 kg/m^2 for calcium, P = 0.77, and −0.0004 ± 0.0001 kg/m^2 for dairy products, P = 0.71). A repeated analysis of 1424 women with plausible reported energy intakes (ratio of energy intake to basal metabolic rate of 1.2 to 2.5) [32], conducted because of possible selective misreporting of dietary intake [33], also showed no relation between intakes of calcium and dairy products and BMI (adjusted means in the lowest and highest quartiles were 20.4 and 20.5 kg/m^2 for calcium, P for trend = 0.73, and 20.3 and 20.4 kg/m^2 for dairy products, P for trend = 0.73; $\beta \pm$ SE 0.0001 ± 0.0008 kg/m^2 for calcium, P = 0.90, and 0.0006 ± 0.0010 kg/m^2 for dairy products, P = 0.54).

Discussion

Using cross-sectional data of relatively lean young Japanese women with relatively low intakes of calcium and dairy products, we found no clear association of intakes of calcium and dairy products with BMI. This finding was consistent regardless of exclusion of implausible energy reporters.

An inverse relation of intakes of calcium and/or dairy products to measurements of obesity has been indicated in a considerable number of case-control [2], cross-sectional [3,5,7–10,12], and longitudinal [1,4,6] studies and intervention trials [13–15] conducted in Western countries. In addition, the frequency of dairy consumption has been inversely associated with BMI in Iranian adults [11]. In contrast, no significant relation has been shown in two longitudinal studies [18,21] or in several intervention trials [17,19,20] in Western countries. A recent longitudinal study

Table 1
Basic characteristics of subjects (n = 1905)*

Variable	
Age (y)	18.1 ± 0.4
Body height (cm)	157.9 ± 5.2
Body weight (kg)	51.8 ± 7.3
Body mass index (kg/m^2)	20.8 ± 2.6
Residential block†	
Kanto II, Hokkaido, and Tohoku	84 (4)
Kanto I	434 (23)
Tokai and Hokuriku	278 (15)
Kinki I	152 (8)
Kinki II	118 (6)
Chugoku	294 (15)
Shikoku	156 (8)
Kita-kyushu	214 (11)
Minami-kyushu	175 (9)
Size of residential area	
City with population ≥1 million	318 (17)
City with population <1 million	1106 (58)
Town and village	481 (25)
Current smoking	
No	1849 (97)
Yes	56 (3)
Current alcohol drinking	
No	1514 (79)
Yes	391 (21)
Physical activity‡	
Sedentary	1647 (86)
Active	258 (14)
Experience of dieting§	
No	1160 (61)
Yes	745 (39)
Intentional dietary change	
No	1481 (78)
Changed within 1 y	213 (11)
Changed within 3 y	127 (7)
Changed >3 y ago	84 (4)
Rate of eating	
Very slow	92 (5)
Relatively slow	431 (23)
Medium	683 (36)
Relatively fast	610 (32)
Very fast	89 (5)
Use of calcium supplement	
No	1868 (98)
Yes	37 (2)
Energy intake (kcal/d)	1911 ± 517
Protein intake (% energy)	13.7 ± 2.2
Fat intake (% energy)	30.5 ± 6.1
Carbohydrate intake (% energy)	54.4 ± 6.8
Dietary fiber intake (g/1000 kcal)	6.3 ± 1.7
Calcium intake (mg/1000 kcal)	268 ± 93
Dairy product intake (g/1000 kcal)	80 ± 63

* Values are means ± standard deviations or numbers of subjects (%).

† Residential blocks were categorized into 12 blocks according to the National Nutrition Survey of Japan [23]. Because relatively few subjects were categorized into three of these blocks (Hokkaido, Tohoku, and Hokuriku), they were included in their adjacent blocks.

‡ Subjects who took part in sports club activities at least once per week were defined as "active" and others as "sedentary."

§ "Dieting" was defined as at least 2 kg of intentional decrease of body weight within 1 mo.

Table 2
Selected characteristics of subjects by quartiles of energy-adjusted intakes of calcium and dairy products (n = 1905)*

Variable	Quartiles of intakes of calcium or dairy products				$P^{\dagger}$
	1 (n = 476)	2 (n = 476)	3 (n = 477)	4 (n = 476)	
Calcium intake (mg/1000 kcal)	166 ± 26	227 ± 15	283 ± 17	394 ± 74	
Current smokers (%)	4	2	3	2	0.27
Current alcohol drinkers (%)	19	22	19	23	0.26
Subjects with active lifestyle (%)	9	15	14	16	0.0019
Subjects with experience of dieting (%)	36	36	43	42	0.0061
Intentional dietary change (%)					<0.0001
No	87	81	77	66	
Changed within 1 y	8	10	11	16	
Changed within 3 y	3	6	8	10	
Changed >3 y ago	2	3	4	8	
Rate of eating (%)					0.0073
Very slow	3	5	4	7	
Relatively slow	21	22	23	24	
Medium	38	33	37	35	
Relatively fast	31	36	31	29	
Very fast	7	3	5	4	
Protein intake (% energy)	12.1 ± 1.9	13.2 ± 1.7	14.1 ± 1.8	15.2 ± 2.1	<0.0001
Fat intake (% energy)	28.4 ± 6.9	31.1 ± 5.7	31.2 ± 5.6	31.1 ± 5.5	<0.0001
Dietary fiber intake (g/1000 kcal)	5.4 ± 1.2	6.0 ± 1.3	6.7 ± 1.5	7.2 ± 2.0	<0.0001
Dairy product intake (g/1000 kcal)	19 ± 8	49 ± 10	86 ± 12	166 ± 59	
Current smokers (%)	3	3	3	3	0.71
Current alcohol drinkers (%)	18	20	23	21	0.14
Subjects with active lifestyle (%)	10	14	14	16	0.0197
Subjects with experience of dieting (%)	40	37	38	42	0.42
Intentional dietary change (%)					<0.0001
No	83	79	80	69	
Changed within 1 y	9	12	9	15	
Changed within 3 y	6	4	6	10	
Changed >3 y ago	3	5	4	6	
Rate of eating (%)					0.14
Very slow	3	5	6	6	
Relatively slow	22	24	21	23	
Medium	39	34	33	38	
Relatively fast	31	33	35	30	
Very fast	6	4	5	4	
Protein intake (% energy)	12.8 ± 2.1	13.5 ± 2.1	13.8 ± 2.1	14.6 ± 2.1	<0.0001
Fat intake (% energy)	28.7 ± 6.6	30.6 ± 6.4	31.5 ± 5.2	31.1 ± 5.6	<0.0001
Dietary fiber intake (g/1000 kcal)	6.1 ± 1.6	6.3 ± 1.7	6.4 ± 1.6	6.5 ± 1.8	0.0045

* Values are mean ± standard deviation unless otherwise indicated.
† For continuous variables, tests for linear trend used the median value in each quartile as a continuous variable in linear regression; a Mantel-Haenszel chi-square test was used for categorical variables.

of American adolescents has also suggested a positive association between milk intake and body weight gain [22]. These inconsistent results may be explained at least in part by the different populations examined, different methods used to assess obesity and dietary intake, and number and type of variables used as confounding factors.

A possible reason for the null association we observed may be due to the narrow BMI range of our subjects, 78% of whom were of normal weight (BMI 18.5 to 24.9 kg/m^2) and only 6% were overweight (BMI ≥ 25 kg/m^2); thus, our population is relatively lean compared with populations in Western countries. Alternatively, it is possible that intakes of calcium and dairy products in our population were too low to have a beneficial effect on BMI; even intake levels of the highest quartile categories were relatively low for calcium (median 373 mg/1000 kcal) and dairy products (141 g/1000 kcal).

We do not believe that our null finding is due to any inaccuracy of our data for the following reasons. First, we used a validated DHQ to assess dietary intake. Second, although we used BMI computed from self-reported rather than measured weight and height, previous research has shown that BMI derived from the former is highly correlated with measured BMI [34,35], suggesting that BMI thus calculated is a reliable measurement for use in correlation analysis. Third, we previously observed a significant association of the self-reported rate of eating and dietary fiber intake with BMI in the same population [26], which may be some evidence of the quality of our data. Fourth, we conducted analyses with and without 481 women with implau-

Table 3
Adjusted mean ± SE of BMI according to quartiles of energy-adjusted intakes of calcium and dairy products with partial regression coefficients (β) and SE expressing changes in BMI for change in energy-adjusted intakes of calcium and dairy products (n = 1905)*

Variable	Quartiles of intakes of calcium or dairy products‡				P for trend†	β ± SE	P
	1 (n = 476)	2 (n = 476)	3 (n = 477)	4 (n = 476)			
Calcium intake (mg/1000 kcal)	170 (74–201)	227 (202–254)	282 (255–314)	373 (315–728)			
BMI (kg/m^2)	20.7 ± 0.1	20.7 ± 0.1	20.9 ± 0.1	20.8 ± 0.1	0.48	−0.0002 ± 0.0008	0.77
Dairy product intake (g/1000 kcal)	19 (0–32)	49 (33–65)	86 (66–108)	141 (109–458)			
BMI (kg/m^2)	20.6 ± 0.1	20.8 ± 0.1	21.1 ± 0.1	20.6 ± 0.1	0.81	−0.0004 ± 0.0001	0.71

BMI, body mass index; SE, standard error

* Adjusted for residential block (Kanto II, Hokkaido, and Tohoku; Kanto I; Tokai and Hokuriku; Kinki I; Kinki II; Chugoku; Shikoku; Kita-kyushu; and Minami-kyushu), size of residential area (city with population ≥ 1 million, city with population < 1 million, and town and village), current smoking (yes or no), alcohol drinking (yes or no), physical activity (sedentary or active), experience of dieting (yes or no), intentional dietary change (no, changed within 1 y, changed within 3 y, or changed >3 y ago), rate of eating (very slow, relatively slow, medium, relatively fast, or very fast), protein intake (percentage of energy, continuous), fat intake (percentage of energy, continuous), and dietary fiber intake (grams per 1000 kcal, continuous).

† Tests for linear trend used the median value in each quartile as a continuous variable in linear regression.

‡ Values are medians (ranges) or means ± SE.

sible energy intake, and these analyses provided similar results.

We could not include calcium intake from dietary supplements in the analysis because of the lack of a reliable composition table of dietary supplement in Japan. However, only 37 of 1905 women (2%) used calcium supplement in the present study. In addition, neither exclusion of calcium supplement users from analysis nor a further adjustment for calcium supplement usage as a dummy variable (yes or no) materially altered the results (data not shown). Thus, it is hardly likely that calcium supplement usage had a major effect on the findings in this study.

Our results may not be extrapolated to general Japanese populations because the subjects were selected female dietetic students who may have been highly health conscious. Other limitations regarding subject characteristics include the narrow range of age (18 to 20 y) and BMI (78% of subjects had a normal BMI, i.e., 18.5 to 24.9 kg/m^2) and the relatively low intakes of calcium and dairy products mentioned above. Possible seasonal changes in dietary habits were not taken into account in the present study because our DHQ assessed dietary habits during the previous month; however, seasonal variations in Japanese women seemed to be relatively minor, at least in calcium intake (7%) [36]. Although we attempted to adjust for a wide range of potential confounding variables, we can not rule out the possibility of residual confounding due to these or poorly measured variables such as physical activity, which was assessed quite roughly, and other unmeasured variables such as parental overweight or obesity, socioeconomic level, and unknown variables.

In conclusion, intakes of calcium and dairy products may not necessarily be associated with BMI among young Japanese women who not only are relatively lean but also have relatively low intakes of calcium and dairy products. However, better-designed cross-sectional studies and prospective and intervention studies should be conducted to confirm our present findings.

References

[1] Lin YC, Lyle RM, McCabe LD, McCabe GP, Weaver CM, Teegarden D. Dairy calcium is related to changes in body composition during a two-year exercise intervention in young women. J Am Coll Nutr 2000;19:754–60.
[2] Tanasescu M, Ferris AM, Himmelgreen DA, Rodriguez N, Perez-Escamilla R. Biobehavioral factors are associated with obesity in Puerto Rican children. J Nutr 2000;130:1734–42.
[3] Zemel MB, Shi H, Greer B, Dirienzo D, Zemel PC. Regulation of adiposity by dietary calcium. FASEB J 2000;14:1132–8.
[4] Carruth BR, Skinner JD. The role of dietary calcium and other nutrients in moderating body fat in preschool children. Int J Obes Relat Metab Disord 2001;25:559–66.
[5] Jacqmain M, Doucet E, Despres JP, Bouchard C, Tremblay A. Calcium intake, body composition, and lipoprotein-lipid concentrations in adults. Am J Clin Nutr 2003;77:1448–52.
[6] Skinner JD, Bounds W, Carruth BR, Ziegler P. Longitudinal calcium intake is negatively related to children's body fat indexes. J Am Diet Assoc 2003;103:1626–31.
[7] Loos RJ, Rankinen T, Leon AS, Skinner JS, Wilmore JH, Rao DC, et al. Calcium intake is associated with adiposity in Black and White men and White women of the HERITAGE Family Study. J Nutr 2004;134:1772–8.
[8] Novotny R, Daida YG, Acharya S, Grove JS, Vogt TM. Dairy intake is associated with lower body fat and soda intake with greater weight in adolescent girls. J Nutr 2004;134:1905–9.
[9] Rosell M, Johansson G, Berglund L, Vessby B, de Faire U, Hellenius ML. Associations between the intake of dairy fat and calcium and abdominal obesity. Int J Obes Relat Metab Disord 2004;28:1427–34.
[10] Barba G, Troiano E, Russo P, Venezia A, Siani A. Inverse association between body mass and frequency of milk consumption in children. Br J Nutr 2005;93:15–9.
[11] Mirmiran P, Esmaillzadeh A, Azizi F. Dairy consumption and body mass index: an inverse relationship. Int J Obes Relat Metab Disord 2005;29:115–21.
[12] Moreira P, Padez C, Mourao I, Rosado V. Dietary calcium and body mass index in Portuguese children. Eur J Clin Nutr 2005;59:861–7.
[13] Summerbell CD, Watts C, Higgins JP, Garrow JS. Randomised controlled trial of novel, simple, and well supervised weight reducing diets in outpatients. BMJ 1998;317:1487–9.
[14] Zemel MB, Thompson W, Milstead A, Morris K, Campbell P. Calcium and dairy acceleration of weight and fat loss during energy restriction in obese adults. Obes Res 2004;12:582–90.

[15] Zemel MB, Richards J, Mathis S, Milstead A, Gebhardt L, Silva E. Dairy augmentation of total and central fat loss in obese subjects. Int J Obes Relat Metab Disord 2005;29:391–7.
[16] Shi H, Dirienzo D, Zemel MB. Effects of dietary calcium on adipocyte lipid metabolism and body weight regulation in energy-restricted aP2-agouti transgenic mice. FASEB J 2001;15:291–3.
[17] Barr SI. Increased dairy product or calcium intake: is body weight or composition affected in humans? J Nutr 2003;133:245S–8.
[18] Phillips SM, Bandini LG, Cyr H, Colclough-Douglas S, Naumova E, Must A. Dairy food consumption and body weight and fatness studied longitudinally over the adolescent period. Int J Obes Relat Metab Disord 2003;27:1106–13.
[19] Shapses SA, Heshka S, Heymsfield SB. Effect of calcium supplementation on weight and fat loss in women. J Clin Endocrinol Metab 2004;89:632–7.
[20] Gunther CW, Legowski PA, Lyle RM, McCabe GP, Eagan MS, Peacock M, et al. Dairy products do not lead to alterations in body weight or fat mass in young women in a 1-y intervention. Am J Clin Nutr 2005;81:751–6.
[21] Boon N, Koppes LL, Saris WH, Van Mechelen W. The relation between calcium intake and body composition in a Dutch population: the Amsterdam Growth and Health Longitudinal Study. Am J Epidemiol 2005;162:27–32.
[22] Berkey CS, Rockett HR, Willett WC, Colditz GA. Milk, dairy fat, dietary calcium, and weight gain: a longitudinal study of adolescents. Arch Pediatr Adolesc Med 2005;159:543–50.
[23] Ministry of Health, Labour and Welfare. The national nutrition survey in Japan, 2002 (in Japanese). Tokyo: Ministry of Health, Labour and Welfare; 2004.
[24] Sasaki S, Tsuji T, Katagiri A, Shimoda T, for the Diets of the Fresh Students in Dietetic Courses Study Group. Association between the number of food items bought in convenience stores and nutrient and food-group intakes—a survey of first-year female college students taking dietetic courses (in Japanese with English abstract). J Jpn Soc Nutr Food Sci 2000;53:215–26.
[25] Sasaki S, Shimoda T, Katagiri A, Tsuji T, Amano K. Eating frequency of rice vs. bread at breakfast and nutrient and food-group intake among Japanese female college students. J Community Nutr 2002;4:83–9.
[26] Sasaki S, Katagiri A, Tsuji T, Shimoda T, Amano K. Self-reported rate of eating correlates with body mass index in 18-y-old Japanese women. Int J Obes Relat Metab Disord 2003;27:1405–10.
[27] Sasaki S, Yanagibori R, Amano K. Self-administered diet history questionnaire developed for health education: a relative validation of the test-version by comparison with 3-day diet record in women. J Epidemiol 1998;8:203–15.
[28] Sasaki S, Yanagibori R, Amano K. Validity of a self-administered diet history questionnaire for assessment of sodium and potassium—comparison with single 24-hour urinary excretion. Jpn Circ J 1998; 62:431–5.
[29] Sasaki S, Ushio F, Amano K, Morihara M, Todoriki T, Uehara Y, et al. Serum biomarker-based validation of a self-administered diet history questionnaire for Japanese subjects. J Nutr Sci Vitaminol 2000;46:285–96.
[30] Science and Technology Agency. Standard tables of food composition in Japan (in Japanese). 5th ed. Tokyo: Printing Bureau of the Ministry of Finance; 2000.
[31] Sasaki S, Tsuji T. Influence of co-habitation on a family line resemblance in nutrient and food-group intake among three generations of Japanese women. J Community Nutr 2003;5:93–104.
[32] Black AE, Coward WA, Cole TJ, Prentice AM. Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. Eur J Clin Nutr 1996;50:72–92.
[33] Okubo H, Sasaki S. Underreporting of energy intake among Japanese women aged 18–20 years and its association with reported nutrient and food group intakes. Public Health Nutr 2004;7:911–7.
[34] Goodman E, Hinden BR, Khandelwal S. Accuracy of teen and parental reports of obesity and body mass index. Pediatrics 2000;106: 52–8.
[35] Kuczmarski MF, Kuczmarski RJ, Najjar M. Effects of age on validity of self-reported height, weight, and body mass index: findings from the Third National Health and Nutrition Examination Survey, 1988–1994. J Am Diet Assoc 2001;101:28–34.
[36] Tokudome Y, Imaeda N, Nagaya T, Ikeda M, Fujiwara N, Sato J, et al. Daily, weekly, seasonal, within- and between-individual variation in nutrient intake according to four season consecutive 7 day weighed diet records in Japanese female dietitians. J Epidemiol 2002;12:85–92.

European Journal of Clinical Nutrition (2007), 1–10

0954-3007/07 $30.00
www.nature.com/ejcn

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.
European Journal of Clinical Nutrition advance online publication 24 January 2007; doi:10.1038/sj.ejcn.1602610

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,

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).
Guarantor: S Sasaki.
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.
Received 25 January 2006; revised 15 November 2006; accepted 15 November 2006

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±0.5%, mean±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±2.2% (mean±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 ⩾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

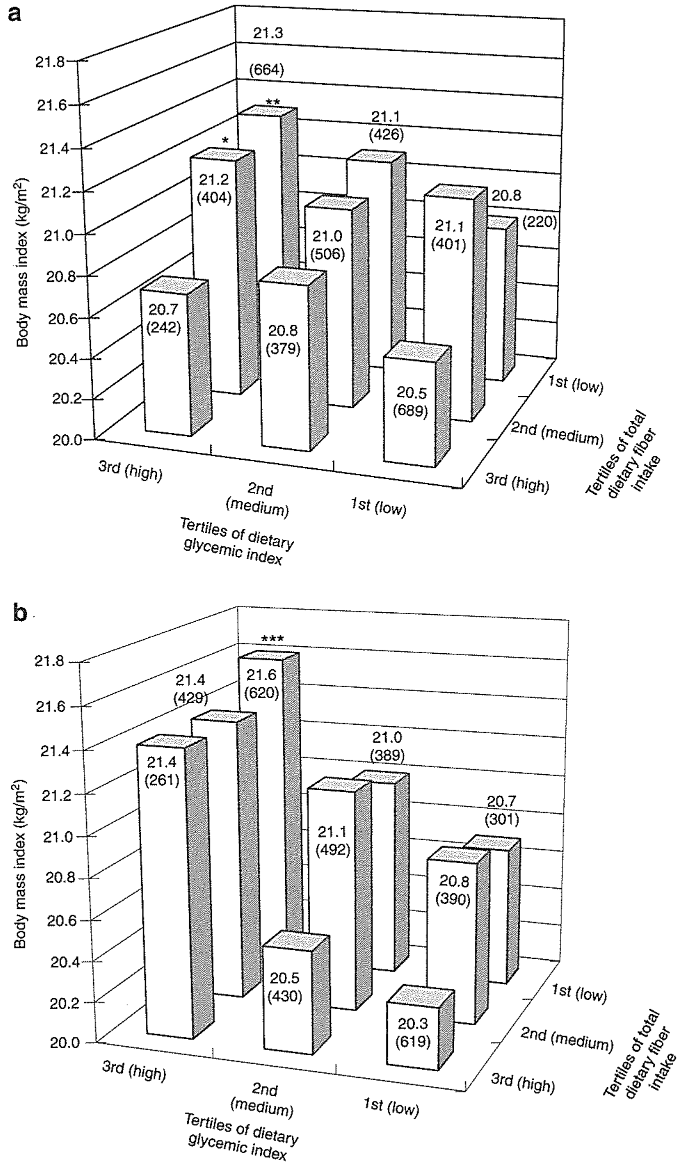

Figure 1 Body mass index by different levels of total dietary fiber intake and dietary glycemic index (GI) (**a**) or glycemic load (GL) (**b**) among the 3931 Japanese women aged 18–20 years. Dietary variables were stratified by tertiles (first (low): <5.5 g/4186 kJ; second (medium): 5.5–6.9 g/4186 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.

Acknowledgements

We thank the students for their generous participation in the study. We also thank Dr M Sugiyama for technical advice regarding glycemic index values for Japanese foods.

References

Amano Y, Kawakubo K, Lee JS, Tang AC, Sugiyama M, Mori K (2004). Correlation between dietary glycemic index and cardiovascular disease risk factors among Japanese women. *Eur J Clin Nutr* **58**, 1472–1478.

Appleby PN, Thorogood M, Mann JI, Key TJ (1998). Low body mass index in non-meat eaters: the possible roles of animal fat, dietary fibre and alcohol. *Int J Obes Relat Metab Disord* **22**, 454–460.

Augustin LS, Franceschi S, Jenkins DJ, Kendall CW, La Vecchia C (2002). Glycemic index in chronic disease: a review. *Eur J Clin Nutr* **56**, 1049–1071.

Black AE, Coward WA, Cole TJ, Prentice AM (1996). Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. *Eur J Clin Nutr* **50**, 72–92.

Bouche C, Rizkalla SW, Luo J, Vidal H, Veronese A, Pacher N *et al.* (2002). Five-week, low-glycemic index diet decreases total fat mass and improves plasma lipid profile in moderately overweight nondiabetic men. *Diabetes Care* **25**, 822–828.

Chew I, Brand JC, Thorburn AW, Truswell AS (1988). Application of glycemic index to mixed meals. *Am J Clin Nutr* **47**, 53–56.

Coulston AM, Hollenbeck CB, Swislocki AL, Reaven GM (1987). Effect of source of dietary carbohydrate on plasma glucose and insulin responses to mixed meals in subjects with NIDDM. *Diabetes Care* **10**, 395–400.

Fernandes G, Velangi A, Wolever TM (2005). Glycemic index of potatoes commonly consumed in North America. *J Am Diet Assoc* **105**, 557–562.

Foster-Powell K, Holt SH, Brand-Miller JC (2002). International table of glycemic index and glycemic load values: 2002. *Am J Clin Nutr* **76**, 5–56.

Goodman E, Hinden BR, Khandelwal S (2000). Accuracy of teen and parental reports of obesity and body mass index. *Pediatrics* **106**, 52–58.

Goris AHC, Westerterp-Plantenga MS, Westerterp KR (2000). Undereating and underrecording of habitual food intake in obese men: selective underreporting of fat intake. *Am J Clin Nutr* **71**, 130–134.

Hashizume N, Ihara H, Kakinoki T, Inage H, Kimura S, Kimura M (2004). Response to blood glucose and insulin by Japanese foods in healthy subjects. *J Jpn Soc Clin Nutr* **25**, 222–225.

Heilbronn LK, Noakes M, Clifton PM (2002). The effect of high- and low-glycemic index energy restricted diets on plasma lipid and glucose profiles in type 2 diabetic subjects with varying glycemic control. *J Am Coll Nutr* **21**, 120–127.

Hollenbeck CB, Coulston AM (1991). The clinical utility of the glycemic index and its application to mixed meals. *Can J Physiol Pharmacol* **69**, 100–107.

Howarth NC, Huang TT, Roberts SB, McCrory MA (2005). Dietary fiber and fat are associated with excess weight in young and middle-aged US adults. *J Am Diet Assoc* **105**, 1365–1372.

Howarth NC, Saltzman E, Roberts SB (2001). Dietary fiber and weight regulation. *Nutr Rev* **59**, 129–139.

Jenkins DJA, Wolever TMS, Taylor RH, Barker H, Fielden H, Baldwin JM *et al.* (1981). Glycemic index of foods: a physiological basis for carbohydrate exchange. *Am J Clin Nutr* **34**, 362–366.

Jimenez-Cruz A, Bacardi-Gascon M, Turnbull WH, Rosales-Garay P, Severino-Lugo I (2003). A flexible, low-glycemic index Mexican-style diet in overweight and obese subjects with type 2 diabetes improves metabolic parameters during a 6-week treatment period. *Diabetes Care* **26**, 1967–1970.

Jonas CR, McCullough ML, Teras LR, Walker-Thurmond KA, Thun MJ, Calle EE (2003). Dietary glycemic index, glycemic load, and risk of incident breast cancer in postmenopausal women. *Cancer Epidemiol Biomarkers Prev* **12**, 573–577.

Kuczmarski MF, Kuczmarski RJ, Najjar M (2001). Effects of age on validity of self-reported height, weight, and body mass index: findings from the Third National Health and Nutrition Examination Survey, 1988–1994. *J Am Diet Assoc* **101**, 28–34.

Liese AD, Schulz M, Fang F, Wolever TM, D'Agostino Jr RB, Sparks KC *et al.* (2005). Dietary glycemic index and glycemic load, carbohydrate and fiber intake, and measures of insulin sensitivity, secretion, and adiposity in the insulin resistance atherosclerosis study. *Diabetes Care* **28**, 2832–2838.

Liu S, Manson JE, Buring JE, Stampfer MJ, Willett WC, Ridker PM (2002). Relation between a diet with a high glycemic load and plasma concentrations of high-sensitivity C-reactive protein in middle-aged women. *Am J Clin Nutr* **75**, 492–498.

Liu S, Willett WC, Manson JE, Hu FB, Rosner B, Colditz G (2003). Relation between changes in intakes of dietary fiber and grain products and changes in weight and development of obesity among middle-aged women. *Am J Clin Nutr* **78**, 920–927.

Liu S, Willett WC, Stampfer MJ, Hu FB, Franz M, Sampson L *et al.* (2000). A prospective study of dietary glycemic load, carbohydrate intake, and risk of coronary heart disease in US women. *Am J Clin Nutr* **71**, 1455–1461.

Livingstone MBE, Black AE (2003). Markers of the validity of reported energy intake. *J Nutr* **133** (suppl 3), 895S–920S.

Ludwig DS, Pereira MA, Kroenke CH, Hilner JE, Van Horn L, Slattery ML *et al.* (1999). Dietary fiber, weight gain, and cardiovascular disease risk factors in young adults. *JAMA* **282**, 1539–1546.

Ma Y, Olendzki B, Chiriboga D, Hebert JR, Li Y, Li W *et al.* (2005). Association between dietary carbohydrates and body weight. *Am J Epidemiol* **161**, 359–367.

Ministry of Health, Labour, Welfare (2004). *The National Nutrition Survey in Japan*. Tokyo: Daiichi Shuppan Publishing Co., Ltd.. (in Japanese).

Ministry of Health, Labour, Welfare (2005). *Dietary Reference Intakes for Japanese*. Tokyo: Daiichi Shuppan Publishing Co., Ltd.. (in Japanese).

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).

Murakami K, Sasaki S, Takahashi Y, Okubo H, Hosoi Y, Horiguchi H *et al.* (2006b). Dietary glycemic index and load in relation to metabolic risk factors in Japanese female farmers with traditional dietary habits. *Am J Clin Nutr* **83**, 1161–1169.

Pereira MA, Ludwig DS (2001). Dietary fiber and body-weight regulation. Observations and mechanisms. *Pediatr Clin North Am* **48**, 969–980.

Rizkalla SW, Taghrid L, Laromiguiere M, Huet D, Boillot J, Rigoir A *et al.* (2004). Improved plasma glucose control, whole-body glucose utilization, and lipid profile on a low-glycemic index diet in type 2 diabetic men: a randomized controlled trial. *Diabetes Care* **27**, 1866–1872.

Sahyoun NR, Anderson AL, Kanaya AM, Koh-Banerjee P, Kritchevsky SB, de Rekeneire N *et al.* (2005). Dietary glycemic index and load, measures of glucose metabolism, and body fat distribution in older adults. *Am J Clin Nutr* **82**, 547–552.

Salmeron J, Ascherio A, Rimm EB, Colditz GA, Spiegelman D, Jenkins DJ *et al.* (1997a). Dietary fiber, glycemic load, and risk of NIDDM in men. *Diabetes Care* **20**, 545–550.

Salmeron J, Manson JE, Stampfer MJ, Colditz GA, Wing AL, Willett WC (1997b). Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women. *JAMA* **277**, 472–477.

Sasaki S, Katagiri A, Tsuji T, Shimoda T, Amano K (2003). Self-reported rate of eating correlates with body mass index in 18-y-old Japanese women. *Int J Obes Relat Metab Disord* **27**, 1405–1410.

Sasaki S, Ushio F, Amano K, Morihara M, Todoriki T, Uehara Y *et al.* (2000). Serum biomarker-based validation of a self-administered diet history questionnaire for Japanese subjects. *J Nutr Sci Vitaminol* **46**, 285–296.

Sasaki S, Yanagibori R, Amano K (1998a). Self-administered diet history questionnaire developed for health education: a relative validation of the test-version by comparison with 3-day diet record in women. *J Epidemiol* **8**, 203–215.

Sasaki S, Yanagibori R, Amano K (1998b). Validity of a self-administered diet history questionnaire for assessment of sodium and potassium: comparison with single 24-hour urinary excretion. *Jpn Circ J* **62**, 431–435.

Scholl TO, Chen X, Khoo CS, Lenders C (2004). The dietary glycemic index during pregnancy: influence on infant birth weight, fetal growth, and biomarkers of carbohydrate metabolism. *Am J Epidemiol* **159**, 467–474.

Schulz M, Liese AD, Mayer-Davis EJ, D'Agostino Jr RB, Fang F, Sparks KC *et al.* (2005). Nutritional correlates of dietary glycaemic index: new aspects from a population perspective. *Br J Nutr* **94**, 397–406.

Schulze MB, Liu S, Rimm EB, Manson JE, Willett WC, Hu FB (2004). Glycemic index, glycemic load, and dietary fiber intake and incidence of type 2 diabetes in younger and middle-aged women. *Am J Clin Nutr* **80**, 348–356.

Science and Technology Agency (2000). *Standard Tables of Food Composition in Japan* 5th edn. Tokyo: Printing Bureau of the Ministry of Finance. (in Japanese).

Sloth B, Krog-Mikkelsen I, Flint A, Tetens I, Bjorck I, Vinoy S *et al.* (2004). No difference in body weight decrease between a low-glycemic-index and a high-glycemic-index diet but reduced LDL cholesterol after 10-wk *ad libitum* intake of the low-glycemic-index diet. *Am J Clin Nutr* **80**, 337–347.

Spencer EA, Appleby PN, Davey GK, Key TJ (2003). Diet and body mass index in 38000 EPIC-Oxford meat-eaters, fish-eaters, vegetarians and vegans. *Int J Obes Relat Metab Disord* **27**, 728–734.

Stookey JD (2001). Energy density, energy intake and weight status in a large free-living sample of Chinese adults: exploring the underlying roles of fat, protein, carbohydrate, fiber and water intakes. *Eur J Clin Nutr* **55**, 349–359.

Sugiyama M, Tang AC, Wakaki Y, Koyama W (2003a). Glycemic index of single and mixed meal foods among common Japanese foods with white rice as a reference food. *Eur J Clin Nutr* **57**, 743–752.

Sugiyama M, Wakaki Y, Nakamoto N, Koyama W, Mitsuhashi F, Inoue M *et al* (2003b). The study of rice and glycemic index. *J Jpn Soc Nutr Care Manage* **3**, 1–15. (in Japanese with English abstract).

Toeller M, Buyken AE, Heitkamp G, Cathelineau G, Ferriss B, Michel G, EURODIAB IDDM Complications Study Group (2001). Nutrient intakes as predictors of body weight in European people with type 1 diabetes. *Int J Obes Relat Metab Disord* **25**, 1815–1822.

Wolever TMS (1990). The glycemic index. *World Rev Nutr Diet* **62**, 120–185.

Wolever TM, Jenkins DJ (1986). The use of the glycemic index in predicting the blood glucose response to mixed meals. *Am J Clin Nutr* **43**, 167–172.

Wolever TM, Jenkins DJ, Jenkins AL, Josse RG (1991). The glycemic index: methodology and clinical implications. *Am J Clin Nutr* **54**, 846–854.

International Journal of Gynecology and Obstetrics (2006) 92, 272–278

International Journal of
GYNECOLOGY
& OBSTETRICS

www.elsevier.com/locate/ijgo

SPECIAL ARTICLE

Maternal weight gain ranges for optimal fetal growth in Japanese women

H. Takimoto [a,*], T. Sugiyama [b], H. Fukuoka [c], N. Kato [d], N. Yoshiike [e]

[a] *Section of Maternal and Child Health, Department of Health Promotion and Research, National Institute of Public Health, Saitama, Japan*
[b] *Department of Obstetrics and Gynecology, Mie University Graduate School of Medicine, Mie, Japan*
[c] *Department of Developmental Medical Sciences, University of Tokyo, Graduate School of Medicine, Tokyo, Japan*
[d] *Department of Education Training Technology and Development, National Institute of Public Health, Saitama, Japan*
[e] *Division of Health and Nutrition Monitoring, National Institute of Health and Nutrition, Tokyo, Japan*

Received 4 August 2005; received in revised form 31 October 2005; accepted 1 December 2005

KEYWORDS
IUGR;
Macrosomia;
Maternal weight gain;
Cross-sectional survey

Abstract

Objective: To identify adequate weight gain ranges during pregnancy in Japanese women. *Method:* Obstetric records from 2001 to 2002 for 46,659 term, singleton, vaginally delivered live births was used to estimate IUGR and macrosomia risk. Total maternal weight gain was grouped according to gestational age-specific percentile values of weight gain as follows: "very low" (under the 25th), "low" (25th to 49th), "moderate" (50th to 74th), "high" (75th to 89th), and "very high" (90th and over). *Results:* About 6% of infants were identified as having IUGR and 0.9% as macrosomia. IUGR risk was elevated with low weight gains. Macrosomia risk was related to high weight gains and previous spontaneous abortions. *Conclusion:* Achieving weight gains between the 50th and 75th percentiles for gestational age was considered adequate for optimal fetal growth in Japanese pregnant women.

1. Introduction

Recent trends in industrialized countries, such as the USA, Canada [1], Sweden [2] and Norway [3], show that infants are born heavier, with increased mean birth weight and a decline in the prevalence of low birth weight (LBW: under 2.5 kg). This

* Corresponding author. Tel.: +81 48 458 6111; fax: +81 48 469 3716.
E-mail address: thidemi@niph.go.jp (H. Takimoto).

0020-7292/$ - see front matter © 2006 International Federation of Gynecology and Obstetrics. Published by Elsevier Ireland Ltd.

doi:10.1016/j.ijgo.2005.12.023

phenomenon has been attributed to an increase in heavier mothers, and decreased maternal smoking in pregnancy. By contrast, the mean birth weight of Japanese infants has steadily declined since the 1980s, despite increasing mean height of young women since World War II. Mean birth weight in male and female infants has decreased from 3.23 kg (males) and 3.14 kg (females) in 1980, to 3.06 kg (males) and 2.98 kg (females) in 2002, and the proportion of LBW has increased from 5.2% in 1980 to 9.0% in 2002. Macrosomia, as defined by a birth weight of 4.0 kg or more, has decreased from 3.0% in 1980 to 1.0% in 2002 [4]. A new fetal growth curve has had to be developed to reflect the changing growth status of Japanese infants [5] because the standard fetal growth curve developed by Nishida et al. in 1984 [6] was no longer applicable due to an increasing number of smaller infants. Moreover, Increase in LBW among term singletons has been observed in the national Children and Infants Growth Survey [7], rising from 2.7% in 1980 to 4.9% in 2000.

This recent trend in reduced fetal size in Japan may be attributed to changes in maternal health. First, maternal smoking in pregnancy had increased from 6.5% in 1990 to 10.9% in 2000 [7]. This is in accordance with the rise in smoking rates among young women. Smoking rates in women aged 20–29 years has increased from 11.9% in 1990 to 20.9% in 2000 [8]. Second, the prevalence of underweight (BMI<18.5 kg/m^2) in young Japanese women has been increasing since 1976 [9]. It has increased from 15.8% in 1976–1980 to 22.9% in 1995–2000 in women aged 20–24 years, and 13.5% to 23.7% in women aged 25–29 years.

In spite of these unfavorable changes regarding maternal and child health, few attempts have been made to enhance fetal growth by promoting greater weight gain during pregnancy. To date, the only weight gain guideline [10] is for the prevention of pregnancy toxemia, not for achieving optimal fetal growth. This study was aimed at newly developing reference weight gain goals in Japanese women, using the 2001–2002 data from the JSOG Perinatal Database.

2. Methods

The data set of 112,257 deliveries in 2001 and 2002 from the 150 obstetric units participating in the Japan Society of Obstetrics and Gynecology (JSOG) Perinatal Database was obtained for analyses. Each year, the Committee requests these units to provide information on maternal health and birth outcome on all deliveries at each unit. No private information on mothers or children is available in this database, which is shared freely by JSOG members for research purposes. This database covered 4.8% of 2,324,517 births which were recorded in the Vital Statistics *reports in* 2001 and 2002 [4].

To determine referent values for weight gain in pregnancy, the data was limited to low-risk singleton term deliveries, according to the exclusion criteria as shown in Table 1. Cesarean deliveries were excluded because most of them were referrals from other hospitals for an emergent delivery. From the remaining cases, 46,659 cases with complete information available on birth weight, infant gender, gestational age (weeks), maternal age, maternal pre-pregnancy and delivery body weight, obstetric history, pregnancy complications (pregnancy-induced hypertension and diabetes), and smoking and drinking history during pregnancy, was selected. Maternal height was not recorded in this database.

The latest JSOG criteria define pregnancy-induced hypertension (PIH) as the first onset of hypertension after 20 weeks gestation [11]. PIH is further categorized into preeclampsia, which is a hypertensive state accompanied by proteinuria, and gestational hypertension, which is a hypertensive state without proteinuria. Proteinuria is defined as urinary protein excretion of 0.3 g/l or greater in a 24-h urine collection. Hypertension is defined as a systolic blood pressure ≧140 mmHg and/or a diastolic blood pressure ≧110 mmHg. As the data was collected before the revision of the PIH criteria, preeclampsia here is hypertension with heavy proteinuria (urinary protein excretion 2.0 g/l or greater).

The 1984 Nishida standard [6] was applied for identification of IUGR in our data. Mean birthweight minus 1.5 S.D. (standard deviations) was selected as a cutoff value for IUGR in this standard

Table 1 Cases excluded from analysis (total number of cases=112,257)

	N	% of total
Cesarean deliveries	30,559	27.2
Delivery method unknown	2258	2.0
Multiple gestations	8387	7.5
Preterm deliveries (<37 weeks)	19,623	17.5
Post-term deliveries (>41 weeks)	623	0.6
Stillbirths and early neonatal deaths[a]	2558	2.3
Maternal deaths	11	0.01
Congenital anomalies of the infant[b]	2449	2.2

[a] Early neonatal death=infant death within 7 days after delivery.
[b] Includes chromosomal disorders.

rather than the 10th percentile, as it is reported to be more relevant to infant morbidity rates [6]. Macrosomia was defined as a birthweight over 4000 g.

Maternal total weight gain was grouped according to the gestational age-specific percentile values of weight gain as follows: "very low" (under the 25th), "low" (25th to 49th), "moderate" (50th to 74th), "high" (75th to 89th), and "very high" (90th and over). Chi-square tests were applied to compare the prevalence of IUGR among different groups. The multivariate logistic model was applied to estimate the odds ratios for significantly related maternal and child factors to IUGR and macrosomia. A p value of less than 0.05 (two-tailed) was considered to be significant. All statistical analyses were performed using the SPSS 11.5J package program (SPSS Japan Inc., Tokyo).

3. Results

The descriptive characteristics of the 46,659 cases fulfilling our inclusion criteria are shown in Table 2. There were 410 cases (0.9%) of macrosomia, including 18 cases of infants weighing 4500 g and over. Four hundred and fifty-seven (1.0%) were conceived through in vitro fertilization (IVF). PIH was observed in 946 cases, and 196 cases of PIH (20.3%) had preeclampsia.

The distribution of birthweight according to infant gender, parity, and gestational age is shown in Table 3, together with the Nishida standards for IUGR [6]. Six percent of cases were identified as having IUGR. In males and females born to primiparas, the 10th percentile values for birth weight were less than 2500 g at 37–38 weeks. The prevalence of LBW and IUGR were higher in females than in males at the same gestational age. LBW prevalence decreased significantly with advanced gestational age in all four groups (p<0.01) grouped by infant gender and parity. IUGR prevalence also decreased with advanced gestational age in males born to primiparas (p<0.01) and in males (p<0.01) and females (p<0.01) born to multiparas. The prevalence of macrosomia increased with advanced gestational age in all four groups.

In order to categorize maternal weight gain according to gestational age, four cutoff values (the 25th, 50th, 75th, and 90th percentiles) for each gestational age were applied, as shown in Table 4. Using these cutoffs, maternal weight gains were categorized into "very low" (under the 25th), "low" (25th to 50th), "moderate" (50th to 74th), "high" (75th to 89th), and "very high" (90th and over). To examine the effect of selected factors on

Table 2 Maternal and infant characteristics of the selected sample

	Selected sample (n=46,659)	2002 National data [4] (n=1,153,855)
Infants		
Male (%)	50.4	51.4
Birth weight (g)[a]	2982±472	3020[b]
Birth weight category		
Very low (<1500 g) (%)	0.07	0.7
Low (1500–2500 g) (%)	6.2	8.3
High (>4000 g) (%)	0.9	1.1
Placental weight (g)[a]	576±112	–
Gestational length (weeks)[a]	39.2±1.1	–
Mothers		
Age at delivery (years)[a]	29.9±4.8	29.8
>34 years old (%)	16.3	12.8
<20 years old (%)	1.8	1.9
Number of prior gestations[a]	1.1±1.2	–
Number of prior deliveries[a]	0.6±0.8	–
Primiparas (%)	53.5	49.5
IVF conception	1.0	–
Past preterm deliveries (%)	1.3	–
Past still births (%)	0.9	–
Past spontaneous abortions (%)	12.6	–
Past cesarean deliveries (%)	1.9	–
Pre-pregnancy weight (kg)[a]	52.2±8.2	–
Delivery weight (kg)[a]	62.1±8.5	–
Total weight gain (kg)[a]	9.9±4.3	–
Pregnancy complications		–
Pregnancy-induced hypertension (%)	2.0	–
Diabetes (%)[c]	1.2	–
Smoking in pregnancy (%)	6.3	–
Drinking in pregnancy (%)	4.6	–

[a] Mean±S.D.
[b] Original data in kg.
[c] Gestational diabetes and pregestational diabetes.

IUGR and macrosomia, the odds ratios (ORs) for each of these factors was calculated by applying logistic regression analysis adjusted for maternal age, parity, pre-pregnancy weight, and infant gender, as shown in Table 5. Compared to the reference "moderate" weight gain group, the ORs for IUGR were significantly high in the "very low" (2.91, 95% CI: 2.59–3.26) and "low" (1.48, 95% CI: 1.34–1.65) weight gain groups. Conception by IVF or prior negative obstetric history, such as preterm deliveries, spontaneous abortions, and stillbirths, were not related to IUGR. Prior cesarean deliveries did not increase IUGR risk. Maternal PIH and diabetes were both significant factors increasing IUGR risk. Preeclamptic mothers presented a higher OR (5.58, 95% CI: 3.92–7.96) for IUGR than mothers with gestational hypertension (2.88, 95% CI: 2.27–3.66). Maternal smoking and drinking both increased IUGR risk.

Compared to the reference "moderate" weight gain group, the ORs for macrosomia were signifi-

Distribution of birthweight (g), according to infant gender, parity and gestational length (weeks)

	Primiparas				Multiparas				
	37 weeks	38 weeks	39 weeks	40 weeks	41 weeks	37 weeks	38 weeks	39 weeks	40 weeks
	N=747	N=1843	N=3691	N=4178	N=1941	N=875	N=2062	N=3492	N=3225
	2619±362	2792±331	2935±337	3049±329	3138±346	2745±346	2896±355	3047±334	3159±357
ıtile	2171	2394	2538	2650	2722	2315	2470	2640	2740
ıtile	2650	2792	2920	3042	3132	2750	2891	3042	3150
ıtile	3056	3191	3360	3468	3566	3184	3340	3468	3590
ht for IUGR[a]	2080	2290	2450	2560	2630	2230	2450	2620	2690
	7.6	5.7	6.1	6.3	6.4	6.4	9.4	8.9	7.5
	31.6	17.7	8.0	4.0	2.5	21.5	11.6	4.4	2.4
ia	0.0	0.1	0.2	0.6	1.1	0.0	0.4	0.5	1.4
	N=908	N=2263	N=3883	N=3861	N=1593	N=1022	N=2382	N=3750	N=2967
	2694±367	2895±341	3042±335	3139±348	3235±350	2832±349	3011±345	3155±341	3283±363
ıtile	2216	2466	2632	2720	2809	2413	2599	2725	2850
ıtile	2697	2891	3048	3130	3230	2820	3002	3144	3276
ıtile	3150	3315	3464	3580	3663	3259	3444	3596	3738
ht for IUGR[a]	2180	2360	2480	2560	2630	2300	2500	2660	2720
	8.4	5.4	4.4	4.0	3.8	4.9	5.7	6.5	5.1
	27.4	11.9	4.8	2.3	1.2	14.5	5.6	1.7	1.3
ia	0.1	0.2	0.3	0.7	1.6	0.4	0.8	1.3	2.4

standard [6].