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A Japanese diet with low glycaemic index and glycaemic load is associated with both favourable and unfavourable aspects of dietary intake patterns in three generations of women

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Abstract
Objective: Western studies have suggested cultural differences in food and nutrient intake patterns associated with dietary glycaemic index (GI) and glycaemic load (GL). Here, we conducted a cross-sectional study to examine the GI and GL of Japanese diets in relation to food and nutrient intakes.
Design: Dietary intake was assessed using a validated, self-administered, diet history questionnaire.
Setting: A total of thirty-five of forty-seven prefectures in Japan.
Subjects: Young (age 18 years), middle-aged (mean age 48 years) and older (mean age 74 years) Japanese women (*n* 3961, 3800 and 2202, respectively).
Results: Irrespective of age, a positive association with dietary GI was seen for white rice only, which contributed most (37–42 %) to the variation in dietary GI. Conversely, all other food groups (such as fruit and vegetable juice, dairy products, noodles and fruit) were negative predictors of dietary GI. For dietary GL, 95–96 % of variation was explained by carbohydrate-rich food groups, all of which were positive predictors of GL. After adjustment for potential confounding factors, only carbohydrate intake was positively associated with dietary GI and GL, irrespective of age. Conversely, dietary GI and GL were inversely associated with intakes of all other nutrients examined (including SFA and Na).
Conclusions: A low-GI and -GL diet, which was characterized principally by a low intake of white rice, was associated with both favourable (higher intakes of dietary fibre and key vitamins and minerals) and unfavourable (higher intakes of SFA and Na) aspects of dietary intake patterns in three generations of Japanese women.

Keywords
Carbohydrate
Glycaemic index
Glycaemic load
Japan
Women
Misreporting

Recent studies have suggested a potential role of diets with a low glycaemic index (GI; a measure of carbohydrate quality)[1] and glycaemic load (GL; a measure of carbohydrate quality and quantity)[2] in the prevention and management of chronic diseases[3], including type 2 diabetes[4]. Findings have not always been consistent, however, particularly with regard to obesity[5–8]. Such heterogeneous results may be at least partly due to cultural differences in dietary intake patterns in relation to dietary GI and GL. In Western populations, dietary GL has generally been associated with many carbohydrate-rich foods, and hence strongly with carbohydrate intake, whereas dietary GI has been associated with not only higher intakes of major carbohydrate-rich foods (such as breads and potatoes) but also lower intakes of other low- or non-carbohydrate foods (such as fruit and dairy products). However, the associations between dietary GI and GL and intake of each of the food groups and nutrients vary considerably in magnitude and direction, depending on different food culture contexts[6–13].

The diets consumed by Japanese people are typically characterized by high intakes of rice, soyabean products, fish, seaweeds and green tea[14]. Further, Japanese diets are known to be high in dietary GI and GL (range of median values: 65–67 and 141–185, respectively; GI for

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glucose = 100)[15–18] compared with Western countries (range of median values: 50–61 and 80–140, respectively; GI for glucose = 100)[3], mainly because white rice, a food with a high GI (77), is the major contributor to dietary GI and GL (46–64 %)[15,16]. Thus, associations of dietary GI and dietary GL with food groups and nutrient intakes may differ between Japanese and Western diets. Information about the nutritional correlates of dietary GI and GL in Japanese populations is scant, however, and this idea remains speculative.

Here, to better understand dietary GI and GL in Japanese populations, we conducted a cross-sectional study of nutritional correlates of dietary GI and GL at both the food group and nutrient level in young, middle-aged, and older Japanese women.

Participants and methods

Survey design

The current cross-sectional study was based on data from the Three-generation Study of Women on Diets and Health, a questionnaire survey conducted in Japan in 2011 and 2012. Details of the study design and survey procedure have been published elsewhere[19]. Briefly, a total of 7016 dietetic students from eighty-five higher education institutions in thirty-five of forty-seven prefectures in Japan were asked to complete two questionnaires on dietary habits and lifestyle factors. Institutions were selected based on the feasibility of the survey, particularly the presence of a collaborator in each institution. We did not conduct any particular sample size calculation but our target was to exceed the size of our previous survey in dietetic students (*n* 4286)[20]. The questionnaires were distributed during the orientation session or first lecture held for freshmen in April 2011 or 2012. Each student was also requested to directly distribute the relevant questionnaires to his/her mother and grandmother and invite them to join the study. Recruitment priority for the grandmother generation was given to the maternal, or if unavailable, paternal grandmother, followed by his/her female acquaintance aged 65–89 years. In total, 4933 students, including 4656 women and 277 men (response rate: 70·3 %), 4044 mothers (57·6 %) and 2332 women from the grandmother's generation (33·2 %) answered both questionnaires.

Analytic sample

We considered that the students (excluding males), mothers and grandmothers (including acquaintances) represented groups of young, middle-aged and older women, respectively.

To analyse young women, we selected female students aged 18 years (*n* 4065) because almost all freshmen in dietetic courses in Japan are 18 years old. We then excluded those living in eastern Japan who participated in the 2011 data collection period, given the influence of the Great East Japan Earthquake in March 2011 (*n* 39); those who answered the questionnaires after 19 May to minimize the influence of dietetic education (*n* 56); and those from one institution at which the response rate was extremely low (2 %; *n* 2). We further excluded those with missing information on the variables of interest (*n* 7).

To analyse middle-aged women, we selected mothers aged ≤60 years (*n* 4012). We then excluded those living in eastern Japan who participated in the 2011 data collection period (*n* 63) and those from the institution with the low response rate (*n* 2). We further excluded those with implausible or missing information on the variables of interest (*n* 147).

To analyse older women, we selected grandmothers (and acquaintances) aged ≥61 years (*n* 2325). The age cut-off point for middle-aged and older women was determined to maximize the number of participants while avoiding overlapping or gapping of the age range. We then excluded those living in eastern Japan who participated in the 2011 data collection period (*n* 47) and those from the institution with the low response rate (*n* 1). We further excluded those with implausible or missing information on the variables of interest (*n* 75). Consequently, the final sample sizes were 3961, 3800 and 2202 for young, middle-aged and older women, respectively. Further exclusion of participants with intentional dietary change within the preceding or current year or in receipt of dietary counselling (592 and 142 young women, 347 and 164 middle-aged women, and 212 and 309 older women, respectively) did not alter the findings of the present study (data not shown); therefore they were included in the present analyses.

Dietary assessment

To assess dietary habits during the preceding month, we used a comprehensive diet history questionnaire (DHQ) for young and middle-aged women[21–23]. For older women we used a brief diet history questionnaire (BDHQ)[21,22] to maximize the response rate and the number of valid responses in this age group, considering the time taken to answer the DHQ and BDHQ (45–60 and 15–20 min, respectively). Responses to the DHQ and BDHQ (and to the lifestyle questionnaire) were checked by survey staff at the study centre. If any missing or implausible responses were found for questions considered essential for analysis, the participant was asked to complete them again. Details of the structure and calculation procedures of the DHQ and BDHQ have been published elsewhere[21–23]. Briefly, the DHQ and BDHQ are structured, self-administered questionnaires that ask about the consumption frequency (and portion size in the DHQ) of selected foods commonly consumed in Japan, as well as general dietary behaviour and usual cooking methods[23,24]. Standard portion sizes in the DHQ and fixed portion sizes in the BDHQ were derived mainly from several recipe books for Japanese dishes[21,23]. The categorization of food groups in the present study is shown in the first column in Supplemental Tables 1 (for DHQ) and 2 (for BDHQ) in the online supplementary material. Food grouping was based on the similarity of nutrient profiles or culinary usage of the foods, mainly according to the *Standard Tables of Food Composition in Japan*[25] and the classification of food groups used in the National Health and Nutrition Survey in Japan[14]. Estimates of the daily intakes of foods (151 items in DHQ and fifty-eight items in BDHQ), energy and selected nutrients were calculated using an *ad hoc* computer algorithm based on the *Standard Tables of Food Composition in Japan*[25]. To minimize the influence of dietary misreporting[26,27], values of dietary intakes were energy-adjusted by the density method (i.e. percentage of energy for energy-providing nutrients and amount per 4184 kJ of energy for other nutrients and foods). The relative validity (particularly ranking ability) of the DHQ and BDHQ has been investigated in ninety-two women aged 31–69 years using a 16 d weighed dietary record as reference[21,22]. Briefly, the median value of Spearman's correlation coefficients for food groups was 0·43 (range: –0·09 to 0·77) for the DHQ and the median value of Pearson's correlation coefficients for nutrients was 0·57 (range: 0·27 to 0·87). Corresponding values for the BDHQ were 0·44 (range: 0·14 to 0·82) and 0·54 (range: 0·34 to 0·87), respectively.

Calculation of dietary glycaemic index and glycaemic load

Calculation methods for dietary GI and GL have been described in detail elsewhere[15,16]. The GI value of each item (as well as the percentage contribution of each food item to dietary GL in the present populations) is shown in the online supplementary material, Supplemental Tables 1 (for DHQ) and 2 (for BDHQ). Briefly, a total of sixty-two (out of 151) food items in the DHQ and twenty (out of fifty-eight) food items in the BHDQ were directly matched to foods available in the GI database, which was developed based on previous publications, including an international table of GI values published in 2002[28–34]. When more than one GI value was available, the mean value was used. Glucose was used as the reference (GI for glucose = 100). Food items for which a GI value had not been determined in previous publications (*n* 10 in the DHQ and *n* 2 in the BDHQ) were assigned the GI value of the closest comparable food (based mainly on macronutrient and fibre content). We excluded alcoholic beverages (*n* 6 in the DHQ and *n* 5 in the BDHQ) from the calculations because their GI values have not been established[35–37]. We also excluded foods with very low or no available carbohydrate content (<3·5 g per standard serving; *n* 73 in the DHQ and *n* 31 in the BDHQ). Thus we assigned them a GI value of 0. Dietary GL was calculated as the sum of the product of the GI value of each food item and the amount of available carbohydrate intake from that food item (g/d) divided by 100. Dietary GI was calculated as dietary GL divided by the total amount of available carbohydrate intake (g/d) and multiplied by 100. For analysis, values of dietary GL, but not dietary GI (which is a measure of carbohydrate quality), were energy-adjusted by the density method (per 4184 kJ). In a group of ninety-two Japanese women aged 31–69 years, the Pearson's correlation coefficient between the DHQ and the 16 d weighed dietary records was 0·50 for dietary GI and 0·57 for dietary GL[16], and the correlation for the BDHQ was 0·39 for dietary GI and 0·43 for dietary GL (S Sasaki and K Murakami, unpublished results), suggesting that the DHQ and BDHQ had satisfactory ranking ability for dietary GI and GL.

Assessment of other variables

All of the variables assessed were based on the participants' self-reported information. Age at the time of the survey was calculated based on birth date. Residential area was grouped into six regions (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; Kyushu) and also into three categories according to population size (city with a population ≥1 million; city with a population <1 million; town and village). Living status (not considered for middle-aged women because almost all lived with family) was grouped into three categories (living alone; living with family; living with others), but for older women those living with others were added to those living with family because of the very small number of participants (*n* 4). BMI was calculated as body weight (in kilograms) divided by the square of body height (in metres). Weight status was grouped into three categories of underweight (BMI: <18·5 kg/m^2), normal weight (BMI: ≥18·5 to < 25·0 kg/m^2) and overweight (BMI: ≥25·0 kg/m^2)[38]. Information on current smoking (yes or no), current alcohol drinking (yes or no), dietary supplement use (yes or no; due to the lack of a reliable composition table of dietary supplements in Japan) and medicine use (yes or no) was also used. Eating out was categorized as ≤3 times/month, once per week, 2–3 times/week or ≥4 times/week (not available in older women). Rate of eating was self-reported according to one of five qualitative categories (very slow; relatively slow; medium; relatively fast; very fast). Physical activity was computed as the average total metabolic equivalent-hours score per day on the basis of the frequency and duration of seven activities (walking; bicycling; standing; running; high-intensity activities; sleeping; sedentary activity) over the preceding months[39] and categorized into quartiles. Occupation was considered for middle-aged women only (housewife; part-time job; full-time job). Except for young women, education level was categorized as low, middle

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and high (≤12 years, 13–15 years and ≥16 years for middle-aged women and ≤9 years, 10–12 years and ≥13 years for older women, respectively). Current marital status (yes or no) was also considered for middle-aged and older women.

Misreporting of energy intake (EI) was evaluated on the basis of the ratio of EI to BMR (Goldberg's cut-off)[40]. Participants were identified as plausible, under- or over-reporters of EI based on whether the individual's ratio was within, below or above the 95 % confidence limits for agreement between EI:BMR and the respective physical activity level (PAL). In the present analysis, PAL for a sedentary lifestyle (i.e. 1·55)[40] was applied for all participants because, in all generations, time spent on sedentary activity (range of mean: 11·65–14·00 h/d) was predominant compared with other activities: walking (1·31–1·95 h/d), bicycling (0·14–0·31 h/d), standing (1·64–2·99 h/d), running (0·02–0·04 h/d), high-intensity activities (0·05–0·06 h/d) and sleeping (6·22–7·97 h/d). BMR was estimated according to an equation specifically developed for Japanese women, as follows: BMR (kJ/d) = (0·0481 × body weight (kg) + 0·0234 × body height (cm) − 0·0138 × age (years) − 0·9708)[41,42]. The 95 % confidence limits for agreement (upper and lower cut-off values) between EI:BMR and PAL were calculated, taking into account the CV in intakes and other components of energy balance (i.e. the within-subject variation in EI, 23 %; precision of the estimated BMR relative to the measured BMR, 8·5 %; and between-subject variation in PAL, 15 %)[40]. Consequently, under-, plausible and over-reporters were defined as having an EI:BMR of <1·09, 1·09–2·21 and >2·21, respectively.

Statistical analysis

All statistical analyses were performed using the statistical software package SAS version 9.3. All reported *P* values are two-tailed and $P < 0·05$ was considered statistically significant. We decided *a priori* to conduct analyses for young, middle-aged and older women separately, mainly due to the use of different dietary assessment methods (i.e. the DHQ for young and middle-aged women and the BDHQ for older women) as well as the differences in potential confounding factors that should be considered. Thus, we did not conduct any formal tests for interaction across age groups. Descriptive data are presented as means and standard deviations for continuous variables and numbers and percentages of participants for categorical variables. Differences in dietary GI and GL across categories of selected characteristics were examined by ANOVA.

Using the PROC REG procedure, stepwise regression analysis was carried out to investigate the contribution of the twenty selected food groups for the DHQ and eighteen food groups for the BDHQ to the inter-individual variation in dietary GI and GL. Multiple linear regression analyses were performed for food groups which contributed to variation by at least 1 % using the PROC REG procedure. These predictive food groups and EI were used as explanatory variables, and dietary GI or GL was used as the response variable. We calculated regression coefficients (with standard errors) of variation in dietary GI and GL by a 100 g increase in intake of each food group, using non-energy-adjusted values.

Multiple linear regression analyses were performed to explore the associations of dietary GI and GL with nutrient intakes. Using the PROC REG procedure, we calculated the adjusted regression coefficients (with standard errors) of variation in intakes of selected nutrients by a 5-unit GI increase and a 10-unit GL increase (per 4184 kJ). Potential confounding factors considered were residential block, size of residential area, weight status, current smoking, current alcohol drinking, dietary supplement use, medication use, physical activity, rate of eating and dietary reporting status. For young women, additional adjustment was made for living status and eating out. For middle-aged women, additional adjustment was made for eating out, occupation, education, current marital status and age (<45, 45–49 or ≥50 years). For older women, additional adjustment was made for living status, education, current marital status and age (61–69, 70–74, 75–79 or ≥80 years). These variables were entered into the model as dummy variables. All of the analyses were also repeated after excluding under- and over-reporters.

Results

Table 1 shows basic and dietary characteristics of the young (age: 18 years), middle-aged (age range: 34–60 years) and older (age range: 61–94 years) women. White rice contributed about half of dietary GL in all generations (mean: 47–53 %; Table 2), followed by sugar and confectioneries, which contributed about one-fifth of dietary GL (20–22 %). Other important contributors (≥3 %) were bread (7–8 %), noodles (4–5 %), other grains (5 %, except for older women), potatoes (5 %, only older women), fruit (4 %, only older women) and soft drinks (3 %, only young women).

Dietary GI and GL differed significantly according to category of many of the selected characteristics (see online supplementary material, Supplemental Table 3). Dietary GI and GL varied by residential block, except for GL in middle-aged women. Size of residential area, physical activity and education were inversely associated with dietary GI and GL, except for no association between GI and size of residential area in young women, or between GI and GL and physical activity in middle-aged women. Irrespective of age, both current alcohol drinkers and dietary supplement users had lower values of GI and GL than the corresponding non-users. Dietary GI and GL differed by eating out category in young and middle-aged women, with the highest values observed in those eating

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Table 1 Basic and dietary characteristics of the study population: young, middle-aged and older women from thirty-five of forty-seven prefectures in Japan, 2011 and 2012

	Young (*n* 3961)		Middle-aged (*n* 3800)		Older (*n* 2202)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	18	0	47·7	3·9	74·4	5·2
Body height (cm)	157·7	5·3	157·3	5·1	150·4	5·5
Body weight (kg)	52·0	7·8	54·5	8·2	51·6	7·9
BMI (kg/m^2)	20·9	2·8	22·0	3·1	22·8	3·2
EI (kJ/d)	7242	2399	7717	2231	7368	2276
EI:BMR	1·47	0·50	1·66	0·49	1·86	0·61
Dietary GI*	64·9	4·4	65·0	4·1	65·1	4·2
Dietary GL (/4184 kJ)*	83·6	15·4	78·0	14·9	86·3	15·8
Food intake (g/4184 kJ)						
White rice	151·0	79·9	134·8	72·1	165·2	69·7
Other grains†	17·0	49·6	15·7	46·0	–	–
Noodles	35·0	33·6	32·9	28·9	30·4	23·9
Bread	18·3	16·6	19·0	16·3	21·0	16·2
Other grain products†	6·7	8·3	6·2	8·1	–	–
Pulses	28·0	30·0	35·0	28·9	47·1	26·6
Potatoes	15·4	11·7	16·4	12·4	32·8	24·2
Sugar and confectioneries	54·3	27·2	47·7	22·6	41·2	25·1
Fat and oil	13·2	7·1	12·7	6·4	8·4	3·8
Fruit	24·7	26·9	31·3	30·6	62·8	43·5
Total vegetables	110·4	66·2	124·4	62·3	181·7	81·7
Fruit and vegetable juice	27·5	60·5	48·5	111·7	20·9	43·1
Alcoholic beverages	1·2	15·0	15·1	36·6	9·8	46·2
Green and black tea	328·3	284·7	285·2	240·8	259·1	178·6
Coffee	19·7	69·6	171·1	162·2	78·5	90·0
Soft drinks	50·8	89·3	28·8	62·9	12·8	52·2
Fish and shellfish	25·4	16·2	30·7	16·1	58·8	31·3
Meat	36·8	19·3	36·4	17·9	32·1	18·0
Eggs	21·0	16·9	18·4	12·2	20·2	12·7
Dairy products	58·9	67·3	69·3	64·3	69·0	55·9
Nutrient intake						
Protein (% of energy)	13·0	2·2	13·7	2·0	16·9	3·2
Total fat (% of energy)	29·4	6·3	29·1	5·9	25·7	5·1
SFA (% of energy)	8·3	2·3	8·0	2·0	6·7	1·6
MUFA (% of energy)	10·4	2·7	10·4	2·5	8·9	2·0
PUFA (% of energy)	6·5	1·6	6·7	1·5	6·3	1·4
Carbohydrate (% of energy)	56·3	7·3	54·2	7·1	55·9	7·4
Alcohol (% of energy)	0·1	0·7	1·8	4·1	0·5	2·3
Dietary fibre (g/4184 kJ)	6·2	2·0	6·7	2·0	8·0	2·2
Cholesterol (mg/4184 kJ)	171	75	165	57	231	76
Na (mg/4184 kJ)	2134	639	2279	618	2557	526
K (mg/4184 kJ)	1030	280	1194	276	1631	400
Ca (mg/4184 kJ)	246	94	267	93	367	112
Mg (mg/4184 kJ)	113	28	131	27	159	33
Fe (mg/4184 kJ)	3·6	0·9	3·7	0·9	5·1	1·2
Vitamin A (μg/4184 kJ)‡	271	206	288	185	475	258
Vitamin E (mg/4184 kJ)§	4·1	1·2	4·2	1·1	4·5	1·0
Folate (μg/4184 kJ)	147	52	156	48	239	75
Vitamin C (mg/4184 kJ)	46·5	23·5	47·9	23·2	85·5	31·3

EI, energy intake; GI, glycaemic index; GL, glycaemic load.
*Based on the GI of glucose (i.e. 100).
†Not available for older women.
‡Retinol equivalents.
§α-Tocopherol.

out ≤3 times/month and the lowest in those eating out 2–3 times/week. There were positive associations between rate of eating and dietary GI and GL in young and middle-aged women. For dietary reporting status, dietary GI and GL were highest in under-reporters and lowest in over-reporters (except for GI in older women). Age was negatively associated with dietary GI ($P = 0·04$) but positively associated with GL ($P = 0·03$) in middle-aged women (data not shown).

Table 3 shows food groups contributing (≥1 %) to the variation in dietary GI or GL. Irrespective of age, only white rice was positively associated with dietary GI, which contributed most (37–42 %) to inter-individual variation in GI. Conversely, all other food groups were negative predictors for dietary GI: fruit and vegetable juice, dairy products, noodles, sugar and confectioneries (except for older women) and fruit (and total vegetable and alcoholic beverages in only older women). In total, these food

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Table 2 Percentage contribution of each food group to dietary glycaemic load in young, middle-aged and older women from thirty-five of forty-seven prefectures in Japan, 2011 and 2012*

	Young (n 3961)			Middle-aged (n 3800)			Older (n 2202)		
	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD
White rice	1	49·19	20·99	1	47·33	20·24	1	52·62	16·50
Sugar and confectioneries	2	20·01	9·44	2	21·60	9·47	2	21·39	11·47
Bread	3	7·35	6·37	3	8·27	6·96	3	7·69	6·16
Noodles	4	5·15	4·97	4	5·27	4·82	5	4·16	3·50
Other grains†	5	4·85	13·89	5	4·76	13·60	–	–	–
Soft drinks	6	3·27	5·24	9	1·99	3·60	10	1·04	3·32
Potatoes	7	2·31	1·90	7	2·47	1·97	4	4·79	3·79
Other grain products†	8	2·30	3·19	8	2·05	2·97	–	–	–
Fruit	9	1·98	2·62	6	2·83	3·01	6	3·91	2·95
Dairy products	10	1·30	1·56	10	1·54	1·59	8	1·22	1·13
Fruit and vegetable juice	11	1·11	2·49	12	0·56	1·36	9	1·06	2·20
Total vegetables	12	0·61	0·92	11	0·68	0·86	7	2·12	1·50
Pulses†	13	0·28	0·64	13	0·31	0·61	–	–	–
Fish and shellfish†	14	0·20	0·32	14	0·31	0·36	–	–	–

*The following food groups were not included in the calculation of dietary glycaemic index and glycaemic load: fat and oil, alcoholic beverages, green and black tea, coffee, meat, eggs and others.
†Not included for older women.

Table 3 Food groups contributing to inter-individual variation in dietary glycaemic index (GI) and glycaemic load (GL) in young, middle-aged and older women from thirty-five of forty-seven prefectures in Japan, 2011 and 2012*

	Young (n 3961)			Middle-aged (n 3800)			Older (n 2202)		
	β†	SE†	Partial R^2	β†	SE†	Partial R^2	β†	SE†	Partial R^2
Dietary GI‡		Model $R^2 = 0·75$			Model $R^2 = 0·71$			Model $R^2 = 0·73$	
White rice	1·96	0·03	0·41	1·69	0·03	0·37	1·99	0·05	0·42
Fruit and vegetable juice	−0·87	0·03	0·11	−0·96	0·05	0·03	−0·77	0·06	0·02
Dairy products	−0·78	0·03	0·08	−0·87	0·03	0·13	−0·90	0·05	0·04
Noodles	−2·08	0·06	0·08	−2·02	0·07	0·09	−1·52	0·10	0·03
Sugar and confectioneries	−0·86	0·07	0·05	−0·79	0·09	0·02	–§	–§	–§
Fruit	−1·46	0·08	0·03	−1·20	0·06	0·06	−1·03	0·07	0·06
Total vegetables	–§	–§	–§	–§	–§	–§	−0·56	0·03	0·13
Alcoholic beverages	–§	–§	–§	–§	–§	–§	−1·17	0·06	0·04
Dietary GL‡		Model $R^2 = 0·95$			Model $R^2 = 0·95$			Model $R^2 = 0·96$	
White rice	24·86	0·14	0·39	26·08	0·15	0·44	25·98	0·21	0·50
Sugar and confectioneries	16·61	0·31	0·29	24·77	0·38	0·24	31·68	0·47	0·35
Other grains	18·50	0·21	0·12	20·71	0·21	0·17	–§	–§	–§
Soft drinks	4·48	0·08	0·05	3·97	0·12	0·01	–§	–§	–§
Bread	30·02	0·55	0·05	31·45	0·52	0·05	28·27	0·80	0·04
Noodles	8·36	0·27	0·02	9·51	0·30	0·02	9·48	0·44	0·02
Potatoes	10·89	0·69	0·01	–§	–§	–§	11·17	0·49	0·03
Other grain products	28·66	0·99	0·01	–§	–§	–§	–§	–§	–§
Fruit	–§	–§	–§	7·18	0·26	0·02	5·04	0·28	0·01

Data presented are regression coefficients (β) with their standard errors and partial determination coefficients (partial R^2).
*Food groups listed are those contributing at least 1 % of the variation of dietary GI or GL based on the stepwise regression analysis with twenty food groups (white rice; other grains; noodles; bread; other grain products; pulses; potatoes; sugar and confectioneries; fat and oil; fruit; total vegetables; fruit and vegetable juice; alcoholic beverages; green and black tea; coffee; soft drinks; fish and shellfish; meat; eggs; dairy products) in young and middle-aged women and eighteen food groups (white rice; noodles; bread; pulses; potatoes; sugar and confectioneries; fat and oil; fruit; total vegetables; fruit and vegetable juice; alcoholic beverages; green and black tea; coffee; soft drinks; fish and shellfish; meat; eggs; dairy products) in older women as explanatory variables and dietary GI or GL as the response variable.
†Models with listed variables and total energy intake as the explanatory variables and dietary GI or GL as the response variable; regression coefficients mean the change of dietary GI or GL with a 100 g increase of intake of each food group.
‡Based on the GI of glucose (i.e. 100).
§Not contributing at least 1 % of the variation of dietary GI or GL.

groups accounted for 71–75 % of the variation in dietary GI. For dietary GL, 95–96 % of the variation was explained by carbohydrate-rich food groups (white rice, sugar and confectioneries, other grains, soft drinks, bread, noodles, potatoes, other grain products) in addition to fruit, all of which were positive predictors for GL.

Table 4 shows the associations of dietary GI and GL with nutrient intakes after adjustment for potential confounding factors. Irrespective of age, only carbohydrate intake was positively associated with dietary GI and GL. Conversely, there were inverse associations of dietary GI and GL with intakes of all other nutrients examined,

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Table 4 Associations of dietary glycaemic index (GI) and glycaemic load (GL) with nutrient intakes in young, middle-aged and older women from thirty-five of forty-seven prefectures in Japan, 2011 and 2012*

	Young (*n* 3961)						Middle-aged (*n* 3800)						Older (*n* 2202)					
	Dietary GI† (5 units)			Dietary GL† (10 units/4184 kJ)			Dietary GI† (5 units)			Dietary GL† (10 units/4184 kJ)			Dietary GI† (5 units)			Dietary GL† (10 units/4184 kJ)		
	β‡	SE‡	*P*	β‡	SE‡	*P*	β‡	SE‡	*P*	β‡	SE‡	*P*	β‡	SE‡	*P*	β‡	SE‡	*P*
Protein (% of energy)	−0·65	0·04	<0·0001	−0·95	0·02	<0·0001	−0·72	0·04	<0·0001	−0·75	0·02	<0·0001	−1·25	0·08	<0·0001	−1·51	0·03	<0·0001
Total fat (% of energy)	−1·81	0·11	<0·0001	−3·54	0·03	<0·0001	−2·03	0·11	<0·0001	−2·92	0·04	<0·0001	−3·17	0·12	<0·0001	−2·85	0·04	<0·0001
SFA (% of energy)	−0·84	0·04	<0·0001	−0·99	0·02	<0·0001	−0·87	0·04	<0·0001	−0·79	0·02	<0·0001	−0·96	0·04	<0·0001	−0·69	0·02	<0·0001
MUFA (% of energy)	−0·44	0·05	<0·0001	−1·38	0·02	<0·0001	−0·53	0·05	<0·0001	−1·15	0·02	<0·0001	−1·07	0·05	<0·0001	−1·03	0·02	<0·0001
PUFA (% of energy)	−0·22	0·03	<0·0001	−0·78	0·01	<0·0001	−0·28	0·03	<0·0001	−0·67	0·01	<0·0001	−0·66	0·04	<0·0001	−0·70	0·01	<0·0001
Carbohydrate (% of energy)	1·90	0·13	<0·0001	4·28	0·03	<0·0001	2·21	0·13	<0·0001	4·30	0·03	<0·0001	4·27	0·17	<0·0001	4·46	0·04	<0·0001
Alcohol (% of energy)	−0·01	0·01	0·30	−0·01	0·01	0·03	0·04	0·07	0·62	−0·81	0·04	<0·0001	−0·47	0·05	<0·0001	−0·27	0·03	<0·0001
Dietary fibre (g/4184 kJ)	−0·79	0·03	<0·0001	−0·40	0·02	<0·0001	−0·79	0·04	<0·0001	−0·29	0·02	<0·0001	−1·09	0·05	<0·0001	−0·40	0·03	<0·0001
Cholesterol (mg/4184 kJ)	−5·31	1·39	0·0002	−23·43	0·73	<0·0001	−6·70	1·13	<0·0001	−16·44	0·58	<0·0001	−25·96	1·94	<0·0001	−31·05	0·84	<0·0001
Na (mg/4184 kJ)	−102·71	11·78	<0·0001	−172·64	6·43	<0·0001	−123·17	12·37	<0·0001	−140·54	6·69	<0·0001	−132·43	13·45	<0·0001	−144·87	6·61	<0·0001
K (mg/4184 kJ)	−151·67	4·48	<0·0001	−99·26	2·53	<0·0001	−144·35	4·95	<0·0001	−79·98	2·80	<0·0001	−252·66	8·92	<0·0001	−133·46	4·74	<0·0001
Ca (mg/4184 kJ)	−51·07	1·52	<0·0001	−29·25	0·90	<0·0001	−53·68	1·61	<0·0001	−24·14	0·96	<0·0001	−63·21	2·62	<0·0001	−40·70	1·30	<0·0001
Mg (mg/4184 kJ)	−16·93	0·43	<0·0001	−8·92	0·26	<0·0001	−15·92	0·48	<0·0001	−7·82	0·28	<0·0001	−17·80	0·78	<0·0001	−11·94	0·38	<0·0001
Fe (mg/4184 kJ)	−0·38	0·02	<0·0001	−0·33	0·01	<0·0001	−0·34	0·02	<0·0001	−0·23	0·01	<0·0001	−0·53	0·03	<0·0001	−0·40	0·01	<0·0001
Vitamin A (μg/4184 kJ)§	−44·50	3·73	<0·0001	−43·30	2·13	<0·0001	−28·92	3·72	<0·0001	−31·05	2·05	<0·0001	−83·17	6·67	<0·0001	−61·05	3·42	<0·0001
Vitamin E (mg/4184 kJ)‖	−0·47	0·02	<0·0001	−0·53	0·01	<0·0001	−0·44	0·02	<0·0001	−0·42	0·01	<0·0001	−0·70	0·02	<0·0001	−0·49	0·01	<0·0001
Folate (μg/4184 kJ)	−14·14	0·93	<0·0001	−13·02	0·52	<0·0001	−12·89	0·94	<0·0001	−10·17	0·52	<0·0001	−34·32	1·81	<0·0001	−17·49	0·96	<0·0001
Vitamin C (mg/4184 kJ)	−7·04	0·41	<0·0001	−3·52	0·25	<0·0001	−5·85	0·45	<0·0001	−2·04	0·26	<0·0001	−17·80	0·72	<0·0001	−5·51	0·41	<0·0001

Data presented are regression coefficients (β) with their standard errors and *P* values.

*Adjustment was made for survey year, residential block, size of residential area, weight status, current smoking, current alcohol drinking, dietary supplement use, medication use, rate of eating, physical activity and dietary reporting status. For young women, additional adjustment was made for living status and eating out. For middle-aged women, additional adjustment was made for eating out, occupation, education, current marital status and age. For older women, additional adjustment was made for living status, education, current marital status and age.

†Based on the GI of glucose (i.e. 100).

‡Regression coefficients mean the change of nutrient intakes with a 5-unit increase of dietary GI or a 10-unit increase of GL (/4184 kJ).

§Retinol equivalents.

‖α-Tocopherol.

including protein, total, saturated, monounsaturated and polyunsaturated fats, alcohol, dietary fibre, cholesterol, Na, K, Ca, Mg, Fe, vitamins A, E and C, and folate (except for no association between GI and alcohol in young and middle-aged women). Exclusion of under- and over-reporters of EI (*n* 1000 in young women, *n* 715 in middle-aged women, *n* 658 in older women) did not substantially change the associations of dietary GI and GL with intakes of food groups and nutrients (data not shown).

Discussion

To our knowledge, the present study is the first to comprehensively examine dietary GI and GL in relation to food group and nutrient intakes in young, middle-aged and older women from a variety of regions in Japan, among whom white rice is a major staple food. Consistent with previous studies[15–18], dietary GI and GL were considerably higher in the Japanese diets than in Western diets[3]. This is highly likely to reflect the differences in the major food contributors to GI and GL. In Western diets these are based on a variety of foods, including breads, pasta, potatoes, sweetened beverages, fruits and breakfast cereals[10–12]. In contrast, the major contributor in Japan is white rice, which has a high GI (i.e. 77). White rice accounted for 47 to 53 % of dietary GI and GL in the present study.

Although the strength and direction of associations of dietary GI and GL with each food group vary considerably in different food culture contexts, Western studies have generally shown that dietary GI is associated with not only a higher intake of major carbohydrate-rich foods (such as bread and potato) but also a lower intake of lower-carbohydrate foods (such as fruit, dairy products and vegetables)[6–10]. Consistent with this, we found that white rice (a major carbohydrate-rich food) was positively associated with dietary GI, while fruit, dairy products, and fruit and vegetable juice (lower-carbohydrate foods) were inversely associated with dietary GI in Japanese women. With regard to dietary GL, Western studies have consistently shown positive associations with many carbohydrate-rich foods[6–10], as was also observed in Japan, where white rice is a major staple food and the proportion of energy intake derived from fat is relatively low compared with Western populations. For both dietary GI and GL, the present study shows that the contribution or influence of white rice is much larger in Japanese women.

Furthermore, associations of dietary GI with intakes of each macronutrient vary across countries. The exceptions to this are protein and dietary fibre, which have consistently shown inverse associations[6–10,13], as was also observed in the present study. For carbohydrate, studies in Dutch adults, Spanish men and European non-diabetic populations have shown positive associations[7,8,10]. Consistent with this, we found a positive association of dietary GI with carbohydrate in the present study. In contrast, a study in US adults showed an inverse association[9] and null relationships were reported in studies of elderly Brazilian adults, British adults and Spanish women[6,8,13]. For total fat, studies of British men and of European non-diabetic populations showed negative associations[6,10], which agree with our findings. Conversely, no association was observed in British women or Spanish men[6,8], while a positive association was observed in Dutch adults, US adults, elderly Brazilian adults and Spanish women[7–9,13]. Higher intakes of alcohol were associated with lower dietary GI in Dutch adults and European non-diabetic populations[7,10]. We observed a similar association only in older women. In contrast, no association was observed in British women[6], while a positive association was shown in British men, US adults and Spanish adults[6,8,9]. These inconsistent findings may at least partly reflect differences in the characteristics and lifestyles of the populations, dietary assessment methods and potential confounding factors considered.

Associations of dietary GL with intakes of each macronutrient appear relatively consistent among Western countries. For example, a strong positive association with carbohydrate and negative associations with protein, total fat and alcohol have been reported in Western studies[6–10,13], which are consistent with our present study. However, while Western studies have generally shown a positive association with dietary fibre[6–10], with one exception[13], we found an inverse association between dietary GL and dietary fibre in our study of Japanese women. This may be due to the much lower intake of whole grains in Japan[43]. On the other hand, it could be speculated that the dietary GL in our study provided little information beyond the carbohydrate content of the diet[6,44,45].

With regard to vitamins and minerals, we found that both dietary GI and GL were inversely associated with all nutrients examined. This may be largely due to the higher white rice intake associated with higher dietary GI and GL, because white rice intake in Japanese diets is inversely associated with the intakes of nutrient-dense foods such as vegetables, fruit, fish and pulses[46,47]. To our knowledge, the associations between dietary GI and GL and micronutrient intakes have not been previously studied.

We observed substantial differences in intakes of several food groups across three generations (e.g. higher intakes of fruit, total vegetables and soft drinks in older women). It is unknown whether this is a reflection of true differences or a function of the use of different dietary assessment questionnaires for young and middle-aged (DHQ) and older (BHDQ) women, albeit that similar findings were reported from the National Health and Nutrition Survey in Japan[14]. Further research across different age groups using the same dietary assessment method would be of interest.

Several limitations of the present study warrant mention. First, given the proportion of Japanese adolescents currently studying in college or university (57 %)[48], our participants (i.e. dietetic students and their mothers and grandmothers/acquaintances) are likely to have a relatively high socio-economic status. Further, dietetic students may be more conscious of their diet or have eating disorders compared with the general population, although the present survey was carried out in most institutions within one month after the dietetic course began to minimize the influence of dietetic education. A further limitation is the low response rate, especially in the grandmother generation (33·2 %), which may have caused self-selection bias. Thus, our results might not be applicable to the general Japanese population.

Second, all self-reported dietary assessment methods are subject to both random and systematic measurement errors. To minimize these errors, we assessed dietary habits during the preceding month using well-established dietary assessment questionnaires with reasonable validity in terms of commonly studied nutritional factors (DHQ and BDHQ)[21–23], as well as the use of energy-adjusted dietary variables[27]. Further, our DHQ and BDHQ were not designed to measure dietary GI and GL specifically, as was the case in other research[7–9,44,45]. In particular, calculations using the BDHQ were based on only twenty-two carbohydrate-containing foods (compared with seventy-two in the DHQ). General limitations to the assignment of appropriate GI values should also be considered. These include the still restricted number of food items in the GI database and the lack of information on differences in the variety, degree of ripeness, composition (e.g. more or less fat), cooking methods and product formulations of the same brand[49]. Moreover, because information on GI values is still limited, we had to assign several foods the GI value of the nearest comparable food for both the DHQ (n 10) and BDHQ (n 2). This is the only feasible approach when the GI value for a food is not available, but these foods were not major contributors to dietary GL in the present populations (≤1 %). Nevertheless, it is evident that both the DHQ[16] and the BDHQ (S Sasaki and K Murakami, unpublished results) have satisfactory ranking ability regarding dietary GI and GL against a 16 d weighted dietary record, as described above. Additionally, as mentioned above, exclusion of EI misreporters did not change the results substantially, which may support the robustness of the present findings.

Finally, although we adjusted for a range of potential confounding factors in the analysis of dietary GI and GL in relation to nutrient intakes, residual confounding could not be ruled out. Further, some of the covariates were not applicable to all groups (e.g. eating out in older women). Nevertheless, results were similar when analysis was restricted to models which considered only the same variables for all three groups (i.e. residential block, size of residential area, weight status, current smoking, current alcohol drinking, dietary supplement use, medication use, physical activity, rate of eating and dietary reporting status; data not shown).

Conclusion

In conclusion, in the current study of young, middle-aged and older Japanese women whose dietary GI and GL are determined primarily on the basis of the GI of white rice, we found that a low-GI and -GL diet was characterized not only by favourable aspects of nutrient intake patterns, such as higher intakes of dietary fibre and key vitamins and minerals, but also by unfavourable aspects, such as higher intakes of total and saturated fats, cholesterol and Na, in all three generations. Thus, ensuring the consumption of a low-GI and -GL diet in Japanese women might not necessarily improve fat and Na intakes. Further research in other Japanese populations (particularly children and men) as well as other Asian populations whose staple food is white rice is warranted.

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manuscript; S.K., H.S. and S.S. contributed to the concept and design of the survey, coordination of the fieldwork, data collection and management, and provided input into the final draft of the manuscript. All authors read and approved the final manuscript. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Ethics Committee of the University of Tokyo's Faculty of Medicine. Written informed consent was obtained from each participant and also from a parent/guardian for participants aged <20 years.

Supplementary material

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