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Monetary costs of dietary energy reported by young Japanese women: association with food and nutrient intake and body mass index

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Abstract

Objective: Little is known about the relationship of monetary diet costs to dietary intake and obesity, particularly in non-Western populations. This study examined monetary cost of dietary energy in relation to diet quality and body mass index (BMI) among young Japanese women.
Design: Dietary intake was assessed by a validated, self-administered, diet history questionnaire. Diet costs were estimated using retail food prices. Monetary cost of dietary energy (Japanese yen 1000 kcal^{-1}) was then calculated. BMI was computed from self-reported body weight and height.
Subjects: A total of 3931 female Japanese dietetic students aged 18–20 years.
Results: Monetary cost of dietary energy was positively associated with intakes of fruits, vegetables, fish and shellfish, and pulses; however, higher monetary cost of dietary energy was also associated with higher consumption of fat and oil, meat and energy-containing beverages, and lower consumption of cereals (rice, bread and noodles) (all P for trend <0.01). At the nutrient level, monetary cost of dietary energy was positively associated with intakes of dietary fibre and key vitamins and minerals, but also associated positively with intakes of fat, saturated fatty acids, cholesterol and sodium, and negatively with carbohydrate intake (all P for trend <0.0001). After adjustment for possible confounders, monetary cost of dietary energy was quite weakly but significantly negatively associated with BMI (P for trend $= 0.0197$).
Conclusions: Increasing monetary cost of dietary energy was associated with both favourable and unfavourable dietary intake patterns and a quite small decrease in BMI in young Japanese women.

Keywords
Monetary cost
Energy intake
Energy density
Nutrient intake
Food intake
Diet quality
Body mass index
Japanese women
Epidemiology

While food choice is influenced by a large number of factors[1], the price of food is clearly an important determinant[2,3]. An inverse relationship exists between the energy density of foods (energy derived from foods per edible weight of foods) and energy cost (monetary cost of foods per energy derived from foods)[4]. Generally, energy-dense and nutrient-dilute foods such as cereals, fats and oils, and sugar and sweets provide dietary energy at the lowest cost. Conversely, the cost per calorie of energy-dilute and nutrient-dense foods including fish and shellfish, vegetables and fruit is much higher.

If healthier foods cost more then so too will healthier diets, suggesting that consumers with limited financial resources might select energy-dense and nutrient-dilute diets as a means of saving money. Observational studies (albeit a limited number) on the cost of freely chosen diets have consistently shown that healthful diets are more expensive than less healthful diets[5–10]. To our knowledge, however, all studies of self-selected diets and monetary costs have been conducted in European countries, with none reported in Asian countries, including Japan.

In contrast to Western populations, Japanese obtain the largest part of their energy intake from rice (29%)[11]. Further, fat intake is relatively low (≤30% energy)[12]. The relationship of dietary costs to dietary intake and diet quality may therefore differ between Western and Japanese populations. Here, we examined the monetary cost of dietary energy in relation to food and nutrient intake and energy density in a group of young Japanese women. Given recent findings from Spain of the higher monetary costs of healthy dietary patterns associated with a lower body mass index (BMI)[10], we also examined the association between monetary cost of dietary energy and BMI.

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Subjects and methods

Subjects and survey procedure

The present study was based on a self-administered questionnaire survey among dietetic students ($n = 4679$) from 54 universities, colleges and technical schools in 33 of 47 prefectures in Japan. Staff at each institution distributed two questionnaires on dietary habits and other lifestyle items during the preceding month at orientation sessions or early lectures for freshman students who entered dietetic courses in April 2005, in most institutions within 2 weeks after the course began. Students filled out the questionnaires during the session, lecture or at home, and then submitted the completed forms to staff at each institution. The staff then checked the responses according to the survey protocol. When missing answers or logical errors were identified, the students were asked to complete the questionnaire again. The staff then mailed the completed questionnaires to the survey centre, where the answers were checked once more. Problematic questionnaires were returned to the staff at the respective institution, and the students were asked to complete the questionnaires again. All questionnaires were thus checked at least once each by staff at the respective institution and at the survey centre. Most surveys were completed by May 2005. The protocol of the 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 two questionnaires (response rate = 93.9%). For the present analysis, we selected female subjects aged 18–20 years ($n = 4060$). We then excluded 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 ($<500\,\text{kcal day}^{-1}$ or $>4000\,\text{kcal day}^{-1}$) ($n = 23$) and those with missing information on the variables used ($n = 12$). As some subjects were in more than one exclusion category, the final analysis sample comprised 3931 women.

Dietary intakes

Dietary habits during the preceding month were assessed using a previously validated, self-administered, diet history questionnaire (DHQ)[13–15]. This is a 16-page structured questionnaire that consists of the following seven sections: general dietary behaviour; major cooking methods; consumption frequency and amount of six alcoholic beverages; consumption frequency and semi-quantitative portion size of 122 selected food and non-alcoholic beverage items; dietary supplements; consumption frequency and semi-quantitative portion size of 19 cereals usually consumed as staple foods (rice, bread and noodles) and *miso* (fermented soybean paste) soup; and open-ended items for foods consumed regularly (once a week or more) but not appearing in the DHQ. Items and portion sizes were derived primarily from data in the National Nutrition Survey of Japan and several recipe books for Japanese dishes[13].

Estimates of dietary intake for 148 food and beverage items, energy and nutrients were calculated using an *ad hoc* computer algorithm for the DHQ based on the *Standard Tables of Food Composition in Japan*[16]. Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation. Energy-adjusted values of dietary intake were calculated using the percentage of energy for macronutrients and the amount per 1000 kcal for dietary fibre, vitamins, minerals and foods. Alcohol intake was not used because of an extremely low mean intake ($0.8\,\text{g day}^{-1}$). Dietary energy density (kcal g^{-1}) was calculated by dividing total energy intake by the estimated edible weight of all foods and caloric beverages consumed (excluding alcohol). Detailed descriptions of the methods used to calculate dietary intake and the validity of the DHQ have been published elsewhere[13–15]. Pearson correlation coefficients between the DHQ and 3-day estimated dietary records were 0.48 for energy, 0.48–0.55 for energy-yielding nutrients (excluding alcohol) and 0.19–0.68 for vitamins and minerals among 47 women[13]. In addition, the Pearson correlation coefficients between the DHQ and 16-day weighed dietary records among 92 women were 0.69 for total dietary fibre, 0.40 for energy density and 0.33 for edible weight consumed, and the Spearman correlation coefficients for food groups ranged from 0.28 to 0.59 (Sasaki S, unpublished observations, 2004).

Dietary costs

Monetary costs of habitual diets obtained from the DHQ ($\text{Japanese yen day}^{-1}$) were calculated by multiplying the amount of food consumed from the DHQ (g day^{-1}) by the estimated price of each food ($\text{Japanese yen g}^{-1}$) and summing the products (1 Japanese yen = 0.007 Euros = 0.008 US dollars in April 2006). The procedure for estimating costs was based on the assumption that all foods were purchased and then prepared and consumed at home. Alcoholic beverages (six items), non-alcoholic and non-caloric beverages (four items), drinking water, noodle soup, and water for *miso* soup were excluded from calculation. The price of each food was obtained mainly from the National Retail Price Survey 2004[17] (122 of 135 items; 90%). This survey is conducted annually in 167 villages, towns and cities, and average prices were calculated as mean values of all survey areas, weighted for population size. For food items whose prices are not published in the National Retail Price Survey (13 of 135 items; 10%), prices were taken from the websites of nationally distributed supermarket (Seiyu, Japan) and fast-food restaurant (McDonalds, Japan and Mister Donut, Japan) chains. Sale prices were not used to determine costs. Costs of combined foods such as pizza were calculated using prices of frozen equivalents. Calculation included correction for preparation and waste

Table 1 Monetary cost of dietary energy of each food*

Food group	Food item (Japanese yen 1000 kcal^{-1})†
Rice	White rice (148), white rice mixed with barley (170), white rice with rice germ (149), 50% polished rice (149), 70% polished rice (148), brown rice (151)
Bread	White bread (154), butter roll (163), croissant (94), pizza (594), Japanese-style pancake (528), pancake (146), cornflakes (260)
Noodles	Japanese noodles (buckwheat and Japanese wheat noodles) (197), instant noodles (418), Chinese noodles (361), spaghetti (126)
Potatoes	Potato chips (268), French fries (466), other potatoes (390), sweet potatoes, yams and taros (624), *konnyaku* (devil's tongue jelly) (8639)
Confectioneries	Rice crackers (301), snacks made from wheat flour (282), Japanese sweets with azuki beans (598), Japanese sweets without azuki beans (564), cakes (758), cookies and biscuits (265), chocolates (242), candies, caramels and chewing gum (1297), jellies (841), doughnuts (411), cake bread (280), jam and marmalade (538), sugar for coffee and tea (48), sugar used during cooking (48)
Fat and oil	Margarine (72), mayonnaise (83), salad dressing (283), oils used during cooking (93), butter (211)
Pulses	Tofu (429), tofu products (582), *natto* (443), boiled beans (216), *miso* as seasoning (179), *miso* in *miso* soup (179), peanuts (247), other nuts (231)
Fish and shellfish	Dried fish (1005), small fish with bones (1534), canned tuna (667), eel (2113), white meat fish (2774), blue-back fish (812), red meat fish (1979), ground fish meat products (1048), shrimp (5498), squid and octopus (2488), oysters (4461), other shellfish (3392), fish eggs (2727), boiled fish, shellfish and seaweed in soy sauce (993), salted fish intestine (1608)
Meat	Ground beef and pork (1093), chicken (782), pork (712), beef (1563), liver (987), ham and sausages (935), bacon (545)
Eggs	Eggs (247)
Dairy products	Full-fat milk (302), low-fat milk (439), skimmed milk (439), sweetened yoghurt (585), non-sweetened yoghurt (632), moderately sweetened yoghurt (608), cheese (436), cottage cheese (1407), ice cream (687), coffee cream (908)
Vegetables	Carrots (825), pumpkins (384), tomatoes (3307), green peppers (3754), broccoli (3329), green leafy vegetables (4203), salted pickled plums (2468), other salted pickles (4195), cabbage (1768), cucumbers (3803), lettuce (4554), Chinese cabbage (1685), bean sprouts (1397), radishes (1045), onions (706), cauliflower (3457), aubergine (3389), burdock (1215), lotus root (2023), tomato juice (1917), vegetable juice (1917), mushrooms (7188), *wakame* seaweed (119 163), laver (9741)
Fruits	Oranges (1287), bananas (387), apples (1030), strawberries (4396), grapes (2385), peaches (2513), pears (1330), persimmons (1038), kiwi fruits (1606), melons (2127), watermelons (1218), raisins (365), canned fruits (480), 100% fruit juice (512), other fruit juice (421)
Non-alcoholic, energy-containing beverages	Cocoa (993), lactic and bacteria beverages (278), soft drinks (528), nutritional supplement drinks (1679)
Other foods	Ketchup (432), non-oil salad dressing (1305), soy sauce (400), curry and roux in stew (182), corn soup (514), Chinese soup (514), nutritional supplement bars (525), artificial sweeteners (2568), table salt (11 (/100 g)), salt used during cooking (11 (/100 g))

*Foods not listed above (six alcoholic beverages, four non-alcoholic and non-caloric beverages, drinking water, noodle soup, water for *miso* soup) were not used for the calculation of diet costs.

†1 Japanese yen = 0.007 Euros = 0.008 US dollars in April 2006.

(e.g. trimming and peeling of vegetables and fruits, removal of bones and skin from fish). Monetary cost of dietary energy (Japanese yen 1000 kcal^{-1}) was calculated by dividing the estimated daily cost of the diet (Japanese yen day^{-1}) by the daily energy intake (kcal day^{-1}) and multiplying by 1000. The monetary cost of dietary energy of each food is listed in Table 1.

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

Residential areas, reported in the 12-page lifestyle questionnaire, were grouped into six regions (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; Kyushu) based on blocks used in the National Nutrition Survey in Japan[12] and hereafter 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; town and village) and hereafter referred to as 'size of residential area'. The lifestyle questionnaire also assessed living status (living alone; living with family; living with others), current smoking (yes; no) and whether currently trying to lose weight (yes; no).

Subjects additionally reported in the questionnaire the time they usually got up and went to bed, which was used to calculate sleeping hours, and the frequency and duration of high- and moderate-intensity activities, walking and sedentary activities. Each activity was assigned a metabolic equivalent task (MET) value from a previously published table, namely 0.9 for sleeping, 7.0 for high-intensity activity, 5.0 for moderate-intensity activity, 3.3 for walking and 1.5 for sedentary activity[18,19]. The number of hours spent per day on each activity was multiplied by its MET value, and all MET-hour products were summed to give a total MET-hour score for the day, which essentially corresponded to the number of kilocalories per kilogram of body weight expended by the individual during the day. The standard value of basal metabolic rate for Japanese people was also expressed as the number of kilocalories per kilogram of body weight expended by an individual during the day. Physical activity level was then calculated by dividing the total MET-hour score by the standard value of basal metabolic rate for Japanese women aged 18–29 years[20]. Current alcohol drinking (yes; no), current dietary supplement use (yes; no) and rate of eating (very slow; relatively slow; medium; relatively fast; very fast) were assessed using the DHQ.

Underreporting of energy intake

Underreporting of energy intake is an ongoing controversy in studies using self-report instruments to collect dietary information[21,22]. To estimate the prevalence of energy underreporting in this population, the ratio of reported energy intake to basal metabolic rate (estimated according to a published equation for Japanese women aged 18–29 years using reported body weight[20]) was computed. Using the Goldberg cut-off method[21] recently re-evaluated by Black[23], a ratio of 1.09 was calculated as the lower cut-off point for reasonable habitual energy intake. Persons with ratios of energy intake to basal metabolic rate <1.09 were considered by this technique to be energy underreporters ($n = 666$; 17%). Results in all subjects and those obtained after exclusion of energy underreporters did not differ materially. Therefore, we only present the analyses of all subjects.

Statistical analysis

All statistical analyses were performed using SAS statistical software, version 8.2 (SAS Institute Inc.). We calculated both crude and multivariate-adjusted means of dietary intake and BMI by quintile categories of monetary cost of dietary energy. Confounding variables included in the multivariate models were residential block (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; Kyushu), size of residential area (city with population ≥1 million; city with population <1 million; town and village), living status (living with family; living alone; living with others), current smoking (yes; no), current alcohol drinking (yes; no), current dietary supplement use (yes; no), currently trying to lose weight (yes; no), rate of eating (very slow; relatively slow; medium; relatively fast; very fast), and physical activity level (continuous) and energy intake (kcal day^{-1}, continuous) for variables except for energy intake. For analyses on BMI, intakes of protein (% of energy, continuous), fat (% of energy, continuous) and dietary fibre (g 1000 kcal^{-1}, continuous) were further included as confounding factors. Linear trends with increasing levels of monetary cost of dietary energy were tested by assigning to each participant the median value for the category and modelling this value as a continuous variable. All reported P-values are two-tailed and were considered statistically significant at the <0.05 level.

Results

Subject characteristics are shown in Table 2. Women in the higher quintiles of monetary cost of dietary energy tended to live in areas with larger populations, live with family, use alcohol and dietary supplements, be slow eaters and trying to lose weight. Women in the higher quintiles of monetary cost of dietary energy had higher mean values of body weight, BMI and physical activity level. Major contributors to total dietary cost were fish and shellfish (16%), meat (16%), vegetables (16%), confectioneries (12%) and rice (9%) (Table 3). Women in the higher quintiles of monetary cost of dietary energy had lower mean values of diet cost for cereals (except noodles). Mean costs of all other foods were higher in women in the higher quintiles of monetary cost of dietary energy.

Table 4 shows the association between monetary cost of dietary energy and dietary intake. Increasing monetary cost of dietary energy was associated with both favourable and unfavourable dietary intake patterns. At the food level, monetary cost of dietary energy was positively associated with consumption of vegetables, fruits, fish and shellfish, pulses, potatoes and dairy products, but also associated positively with intakes of fat and oil, meat and energy-containing beverages, and negatively with intakes of cereals (rice, bread and noodles) (all P for trend <0.01). At the nutrient level, monetary cost of dietary energy was directly associated with intakes of protein, dietary fibre and key vitamins (such as vitamins A, D, E, C, thiamin and riboflavin) and minerals (such as potassium, iron, calcium and magnesium), while monetary cost of dietary energy was associated positively with intakes of fat, saturated fatty acids, cholesterol and sodium, and negatively with carbohydrate intake (all P for trend <0.0001). Monetary cost of dietary energy was positively associated with both energy intake and edible weight consumed (both P for trend <0.0001), but the magnitude of differences between quintiles was larger in edible weight consumed than in energy intake. As a result, monetary cost of dietary energy was negatively associated with energy density (P for trend <0.0001). Adjustment for possible confounding factors did not materially change the associations between monetary cost of dietary energy and dietary intakes (data not shown) except for noodles (P for trend = 0.88), confectioneries (P for trend = 0.0076; negative relationship) and dairy products (P for trend = 0.07).

Table 5 shows the association between monetary cost of dietary energy and BMI. Monetary cost of dietary energy was quite weakly but significantly negatively associated with BMI in both crude (model 1: P for trend = 0.0224) and multivariate (model 2: P for trend = 0.0197) analyses.

Table 2 Subject characteristics according to quintile category of monetary cost of dietary energy*

		Quintile category of monetary cost of dietary energy (Japanese yen 1000 kcal^{-1})†					
	Total (n = 3931)	1st (n = 786) (219–400)	2nd (n = 786) (401–445)	3rd (n = 786) (446–486)	4th (n = 787) (487–537)	5th (n = 786) (538–1389)	*P*‡
Monetary cost of dietary energy (Japanese yen 1000 kcal^{-1})	472 ± 89	360 ± 32	424 ± 13	466 ± 11	511 ± 15	601 ± 74	<0.0001
Median monetary cost of dietary energy (Japanese yen 1000 kcal^{-1})	466	366	424	466	511	580	
Age (years)	18.1 ± 0.3	18.1 ± 0.4	18.1 ± 0.3	18.1 ± 0.3	18.1 ± 0.3	18.1 ± 0.3	0.30
Body height (cm)	157.9 ± 5.3	158.0 ± 5.3	157.9 ± 5.4	157.7 ± 5.4	157.9 ± 5.3	158.0 ± 5.3	0.86
Body weight (kg)	52.3 ± 7.7	52.5 ± 7.7	52.7 ± 8.0	52.0 ± 7.3	52.4 ± 7.8	51.9 ± 7.6	0.05
Body mass index (kg m^{-2})	21.0 ± 2.8	21.1 ± 2.9	21.1 ± 2.8	20.9 ± 2.7	21.0 ± 3.0	20.8 ± 2.7	0.02
Physical activity level	1.45 ± 0.16	1.43 ± 0.14	1.44 ± 0.16	1.45 ± 0.17	1.45 ± 0.14	1.46 ± 0.16	<0.0001
Residential block							0.92
Hokkaido and Tohoku	386 (10)	84 (11)	94 (12)	65 (8)	69 (9)	74 (9)	
Kanto	1351 (34)	246 (31)	259 (33)	281 (36)	279 (36)	286 (37)	
Hokuriku and Tokai	544 (14)	123 (16)	117 (15)	99 (13)	102 (13)	103 (13)	
Kinki	780 (20)	136 (17)	154 (20)	172 (22)	171 (22)	147 (19)	
Chugoku and Shikoku	424 (11)	111 (14)	91 (12)	86 (11)	61 (8)	75 (10)	
Kyushu	446 (11)	86 (11)	71 (9)	84 (11)	104 (13)	101 (13)	
Size of residential area							0.01
City with population ≥1 million	782 (20)	132 (17)	146 (19)	160 (20)	163 (21)	181 (23)	
City with population <1 million	2550 (65)	534 (68)	513 (65)	520 (66)	483 (61)	500 (64)	
Town and village	599 (15)	120 (15)	127 (16)	107 (14)	140 (18)	105 (13)	
Living status							<0.0001
Living with family	3484 (89)	607 (77)	690 (88)	726 (92)	718 (91)	743 (95)	
Living alone	365 (9)	155 (20)	75 (10)	47 (6)	56 (7)	32 (4)	
Living with others	82 (2)	24 (3)	21 (3)	13 (2)	13 (2)	11 (1)	
Current smoking							0.26
No	3873 (99)	773 (98)	771 (98)	776 (99)	776 (99)	777 (99)	
Yes	58 (1)	13 (2)	15 (2)	10 (1)	11 (1)	9 (1)	
Current alcohol drinking							0.007
No	3178 (81)	654 (83)	644 (82)	636 (81)	628 (80)	616 (78)	
Yes	753 (19)	132 (17)	142 (18)	150 (19)	159 (20)	170 (22)	
Current dietary supplement use							<0.0001
No	3206 (82)	677 (86)	668 (85)	629 (80)	625 (79)	608 (77)	
Yes	725 (18)	109 (14)	118 (15)	157 (20)	162 (21)	178 (23)	
Currently trying to lose weight							<0.0001
No	2511 (64)	558 (71)	524 (67)	499 (63)	476 (60)	453 (58)	
Yes	1420 (36)	228 (29)	262 (33)	287 (37)	311 (40)	333 (42)	
Rate of eating							<0.0001
Very slow	241 (6)	36 (5)	33 (4)	43 (5)	67 (9)	62 (8)	
Relatively slow	1077 (27)	197 (25)	194 (25)	226 (29)	222 (28)	239 (30)	
Medium	1149 (29)	245 (31)	251 (32)	220 (28)	210 (27)	223 (28)	
Relatively fast	1303 (33)	263 (33)	279 (36)	264 (34)	262 (33)	234 (30)	
Very fast	161 (4)	45 (6)	29 (4)	33 (4)	26 (3)	28 (4)	

*Values are mean ± standard deviation or number of subjects (%).

†1 Japanese yen = 0.007 Euros = 0.008 US dollars in April 2006.

‡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.

Table 3 Total dietary cost according to quintile category of monetary cost of dietary energy*

	Total ($n = 3931$)	Quintile category of monetary cost of dietary energy (Japanese yen 1000 kcal^{-1})† 1st ($n = 786$) (219–400)	2nd ($n = 786$) (401–445)	3rd ($n = 786$) (446–486)	4th ($n = 787$) (487–537)	5th ($n = 786$) (538–1389)	*P* for trend‡
Total cost (Japanese yen day^{-1})	871 ± 328	586 ± 171	744 ± 191	867 ± 218	978 ± 266	1178 ± 387	<0.0001
Cost of each food (Japanese yen day^{-1})							
Rice	69 ± 31	85 ± 39	72 ± 28	69 ± 27	62 ± 24	58 ± 27	<0.0001
Bread	33 ± 28	34 ± 30	35 ± 31	35 ± 27	35 ± 28	28 ± 23	<0.0001
Noodles	22 ± 20	21 ± 22	23 ± 20	24 ± 21	23 ± 21	22 ± 19	0.33
Potatoes	19 ± 16	12 ± 9	17 ± 12	20 ± 18	22 ± 14	24 ± 21	<0.0001
Confectioneries	104 ± 70	81 ± 55	97 ± 64	110 ± 72	118 ± 79	112 ± 73	<0.0001
Fat and oil	22 ± 14	17 ± 14	20 ± 13	22 ± 12	24 ± 14	25 ± 15	<0.0001
Pulses	25 ± 21	17 ± 17	21 ± 18	25 ± 18	28 ± 20	35 ± 26	<0.0001
Fish and shellfish	140 ± 102	66 ± 39	102 ± 48	133 ± 58	162 ± 73	236 ± 152	<0.0001
Meat	139 ± 93	83 ± 46	117 ± 64	143 ± 79	166 ± 93	183 ± 127	<0.0001
Eggs	12 ± 10	10 ± 10	12 ± 10	13 ± 10	13 ± 10	13 ± 11	<0.0001
Dairy products	73 ± 63	51 ± 40	68 ± 52	76 ± 57	80 ± 59	90 ± 92	<0.0001
Vegetables	140 ± 99	68 ± 39	101 ± 50	126 ± 54	160 ± 75	243 ± 137	<0.0001
Fruits	47 ± 46	23 ± 23	36 ± 32	44 ± 35	55 ± 45	77 ± 65	<0.0001
Non-alcoholic, energy-containing beverages	18 ± 32	13 ± 27	16 ± 29	18 ± 32	20 ± 32	21 ± 38	<0.0001

*Values are mean ± standard deviation.

†1 Japanese yen = 0.007 Euros = 0.008 US dollars in April 2006.

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

This negative relationship remained statistically significant after further adjustment for macronutrient and dietary fibre intakes (model 3: *P* for trend = 0.0301).

Discussion

To date, no information has appeared on the association between dietary costs and diet quality in Japanese populations, among whom rice is a major staple food and whose proportion of energy intake derived from fat is relatively low compared with Western people. In this study of young Japanese women, increasing monetary cost of dietary energy was associated with both favourable and unfavourable dietary intake patterns. Additionally, monetary cost of dietary energy was quite weakly inversely associated with BMI after controlling for possible confounders.

We found that higher monetary cost of dietary energy was associated with higher consumption of not only 'healthy' foods such as vegetables, fruits, fish and shellfish, and pulses, but also 'unhealthy' foods such as fat and oil, meat and energy-containing beverages. Increasing monetary cost of dietary energy was also associated with decreased intake of cereals, particularly rice. These findings are not consistent with previous Western studies. Diets high in fruits and vegetables and low in fats and sweets were associated with higher diet costs in French adults[7]. A study of UK women found that high adherence to a healthy dietary pattern was associated with higher monetary costs[6]. For Japanese people, cereals (particularly rice) are staple foods and are consumed at almost every meal, accompanied by a main and several side dishes consisting of mainly fish and shellfish, meat, egg, vegetables and pulses. Cereals are relatively inexpensive compared with the component foods of main and side dishes in Japan, as shown in Table 1. It might be suggested that persons with limited money available for foods mainly consume cereals (mainly rice) with a poor amount or variety of main and side dishes, while persons with affordable money for foods increase the amount or variety of main and side dishes with decreasing consumption of cereals (mainly rice). This hypothesis might be supported by the decreasing consumption of rice and increasing consumption of other foods such as meat, vegetables, fish and shellfish, and pulses[24] with the observed increase of Gross National Product[25] in Japan from 1955 to 2000.

For nutrients, a dietary survey of French adults found that higher diet costs were associated with more nutrient-dense diets[9]. High-fat diets were less expensive than low-fat diets in Danish children[5] and French adults[7]. These findings in Western populations are again inconsistent with our observations. We found that while higher monetary cost of dietary energy was associated with favourable nutrient intake patterns (higher consumption

Table 4 Dietary intake according to quintile category of monetary cost of dietary energy*

		Quintile category of monetary cost of dietary energy (Japanese yen 1000 kcal^{-1})†					
	Total (n = 3931)	1st (n = 786) (219–400)	2nd (n = 786) (401–445)	3rd (n = 786) (446–486)	4th (n = 787) (487–537)	5th (n = 786) (538–1389)	P for trend‡
Food intake (g 1000 kcal^{-1})							
Rice	159 ± 70	212 ± 79	171 ± 64	154 ± 58	136 ± 56	121 ± 52	<0.0001
Bread	26 ± 20	32 ± 26	29 ± 22	26 ± 18	25 ± 17	20 ± 16	<0.0001
Noodles	37 ± 33	38 ± 38	38 ± 33	38 ± 32	36 ± 29	34 ± 30	0.0024
Potatoes	16 ± 11	11 ± 8	14 ± 8	16 ± 10	18 ± 11	21 ± 15	<0.0001
Confectioneries	39 ± 18	38 ± 21	40 ± 19	41 ± 18	41 ± 17	38 ± 16	0.94
Fat and oil	13 ± 7	12 ± 8	13 ± 7	13 ± 6	14 ± 6	14 ± 6	<0.0001
Pulses	25 ± 18	19 ± 16	23 ± 18	24 ± 16	26 ± 17	32 ± 19	<0.0001
Fish and shellfish	30 ± 18	17 ± 9	24 ± 10	29 ± 11	34 ± 13	47 ± 23	<0.0001
Meat	34 ± 17	24 ± 12	31 ± 14	34 ± 15	39 ± 17	41 ± 20	<0.0001
Eggs	18 ± 14	17 ± 15	19 ± 15	19 ± 13	18 ± 13	18 ± 13	0.87
Dairy products	84 ± 71	75 ± 76	85 ± 74	86 ± 70	83 ± 66	88 ± 68	0.0025
Vegetables	127 ± 82	72 ± 35	99 ± 46	115 ± 48	142 ± 66	207 ± 113	<0.0001
Fruits	50 ± 51	31 ± 41	44 ± 53	47 ± 41	56 ± 51	69 ± 59	<0.0001
Non-alcoholic, energy-containing beverages	33 ± 53	28 ± 41	31 ± 44	35 ± 57	27 ± 54	36 ± 64	0.0003
Nutrient intake							
Protein (% of energy)	13.3 ± 2.1	11.5 ± 1.6	12.6 ± 1.5	13.2 ± 1.5	13.8 ± 1.6	15.3 ± 2.2	<0.0001
Fat (% of energy)	30.0 ± 5.9	26.3 ± 6.3	29.4 ± 5.4	30.6 ± 5.2	31.8 ± 5.2	32.0 ± 5.5	<0.0001
Saturated fatty acid (% of energy)	8.0 ± 2.1	7.0 ± 2.1	7.9 ± 1.9	8.3 ± 2.0	8.6 ± 1.9	8.5 ± 2.0	<0.0001
Carbohydrate (% of energy)	55.2 ± 6.8	60.1 ± 6.8	56.4 ± 5.8	54.8 ± 5.6	53.1 ± 5.7	51.8 ± 6.7	<0.0001
Total dietary fibre (g 1000 kcal^{-1})	6.5 ± 2.0	5.3 ± 1.3	5.8 ± 1.3	6.2 ± 1.5	6.7 ± 1.7	8.1 ± 2.7	<0.0001
Cholesterol (mg 1000 kcal^{-1})	165 ± 64	140 ± 67	160 ± 63	167 ± 59	173 ± 56	183 ± 65	<0.0001
Sodium (mg 1000 kcal^{-1})	2093 ± 547	1805 ± 515	1989 ± 495	2059 ± 452	2202 ± 505	2410 ± 565	<0.0001
Potassium (mg 1000 kcal^{-1})	1099 ± 302	838 ± 174	987 ± 184	1069 ± 185	1179 ± 219	1421 ± 345	<0.0001
Calcium (mg 1000 kcal^{-1})	273 ± 102	222 ± 93	257 ± 92	271 ± 89	284 ± 90	332 ± 112	<0.0001
Magnesium (mg 1000 kcal^{-1})	118 ± 29	99 ± 23	109 ± 23	117 ± 25	123 ± 23	142 ± 32	<0.0001
Iron (mg 1000 kcal^{-1})	3.7 ± 0.9	3.1 ± 0.7	3.4 ± 0.7	3.7 ± 0.6	3.9 ± 0.7	4.5 ± 1.0	<0.0001
Vitamin A (μg 1000 kcal^{-1})	260 ± 169	174 ± 114	220 ± 104	249 ± 113	280 ± 124	377 ± 259	<0.0001
Vitamin D (mg 1000 kcal^{-1})	3.6 ± 2.0	2.3 ± 1.3	3.0 ± 1.6	3.5 ± 1.5	3.9 ± 1.6	5.2 ± 2.6	<0.0001
Vitamin E (mg 1000 kcal^{-1})	5.4 ± 1.3	4.3 ± 1.1	5.0 ± 1.0	5.3 ± 0.9	5.8 ± 1.1	6.5 ± 1.3	<0.0001
Thiamin (mg 1000 kcal^{-1})	0.4 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	<0.0001
Riboflavin (mg 1000 kcal^{-1})	0.7 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.8 ± 0.2	<0.0001
Vitamin C (mg 1000 kcal^{-1})	47 ± 22	32 ± 13	39 ± 16	44 ± 15	52 ± 18	67 ± 27	<0.0001
Energy intake (kcal day^{-1})	1822 ± 504	1625 ± 441	1753 ± 445	1859 ± 464	1912 ± 511	1960 ± 577	<0.0001
Edible weight consumed (g day^{-1})	1439 ± 461	1179 ± 359	1330 ± 358	1440 ± 385	1526 ± 430	1719 ± 552	<0.0001
Energy density (kcal g^{-1})	1.29 ± 0.22	1.40 ± 0.24	1.33 ± 0.21	1.30 ± 0.21	1.26 ± 0.19	1.16 ± 0.20	<0.0001

*Values are mean ± standard deviation.

†1 Japanese yen = 0.007 Euros = 0.008 US dollars in April 2006.

‡Tests for linear trend used the median value in each quintile as a continuous variable in linear regression. Adjustment for possible confounding variables, including physical activity level (continuous), residential block (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; Kyushu), size of residential area (city with ≥1 million; city with <1 million; town and village), living status (living with family; living alone; living with others), current smoking (yes; no), current alcohol drinking (yes; no), current dietary supplement use (yes; no), currently trying to lose weight (yes; no), and rate of eating (very slow; relatively slow; medium; relatively fast; very fast) and energy intake for variables except for energy intake (kcal day^{-1}, continuous), did not change the results materially with the exception of noodles (P or trend = 0.88), confectioneries (P for trend = 0.0076; negative relationship) and dairy products (P for trend = 0.07).

Table 5 Body mass index according to quintile category of monetary cost of dietary energy ($n = 3931$)*

	Quintile category of monetary cost of dietary energy (Japanese yen 1000 kcal^{-1})†					
	1st ($n = 786$) (219–400)	2nd ($n = 786$) (401–445)	3rd ($n = 786$) (446–486)	4th ($n = 787$) (487–537)	5th ($n = 786$) (538–1389)	P for trend‡
Body mass index (kg m^{-2})						
Model 1§	21.0 ± 0.1	21.1 ± 0.1	20.9 ± 0.1	21.0 ± 0.1	20.8 ± 0.1	0.0224
Model 2¶	21.1 ± 0.1	21.1 ± 0.1	20.9 ± 0.1	21.0 ± 0.1	20.8 ± 0.1	0.0197
Model 3‖	21.1 ± 0.1	21.1 ± 0.1	20.9 ± 0.1	21.0 ± 0.1	20.7 ± 0.1	0.0301

*Values are mean ± standard error.

†1 Japanese yen = 0.007 Euros = 0.008 US dollars in April 2006.

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

§Crude model.

¶Adjusted for physical activity level (continuous), residential block (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; Kyushu), size of residential area (city with ≥1 million; city with <1 million; town and village), living status (living with family; living alone; living with others), current smoking (yes; no), current alcohol drinking (yes; no), current dietary supplement use (yes; no), currently trying to lose weight (yes; no), rate of eating (very slow; relatively slow; medium; relatively fast; very fast) and energy intake (kcal day^{-1}, continuous).

‖Adjusted for variables used in the model 2 and intakes of protein (% of energy, continuous), fat (% of energy, continuous) and dietary fibre (g 1000 kcal^{-1}, continuous).

of protein, dietary fibre and key vitamins and minerals), there was also a positive association for dietary fat (and saturated fat and cholesterol) and sodium and a negative association for carbohydrate. The higher fat and lower carbohydrate intake with increasing monetary cost of dietary energy seemed to be due largely to decreasing consumption of cereals (particularly rice). Higher intake of sodium might be due to higher intakes of vegetables, meat, fish and shellfish, and pulses, because in Japan these foods are usually accompanied by seasonings of salty taste, such as salt, soy sauce, *miso* and dressings; actually, intakes of these foods were positively correlated with sodium intake in the present study (Pearson correlation coefficient = 0.13–0.43; median = 0.33).

Our finding that monetary cost of dietary energy is inversely associated with dietary energy density reflects the results of a number of other studies. Two French studies also found that energy-dense diets are associated with lower diet costs[8,9]. Dietary energy density is largely determined by the water content of foods[26]; unlike packaged energy-dense foods, which are dry and tend to have a stable shelf life (including cereals, confectioneries, and fat and oil)[8], transport, storage and wastage costs are all higher for perishable fresh produce (i.e. energy-dilute foods such as fish and shellfish, vegetables and fruit). Thus, the generally observed inverse association between energy cost and energy density can be explained by the fact that, on an energy content basis, energy-dense foods are clearly less costly than energy-dilute foods[8]. However, although energy density and energy intake have previously constantly been shown to be positively linked, both in experimental and epidemiological studies in Western countries[27], a higher energy intake was associated with a lower energy density because energy intake was positively but energy density was negatively associated with monetary cost of dietary energy in the present study. This seemed to be due to the phenomenon that monetary cost of dietary energy was positively associated with both energy intake and edible weight consumed, and the magnitude of differences between quintiles was larger in edible weight consumed than in energy intake. This important point of disagreement between Western and Japanese studies needs to be addressed in future studies.

A Spanish study reported an association between the higher monetary costs of healthy dietary patterns and lower BMI[10]. Although higher monetary cost of dietary energy was not necessarily associated with healthier dietary intake patterns, there was a significant independent negative relationship between monetary cost of dietary energy and BMI in the present study. However, although the association was statistically significant, the magnitude of differences in BMI between quintiles of monetary cost of dietary energy was quite low. Additionally, our subjects were lean compared with Western populations and their BMI values have been reported, not measured, although a high correlation of BMI calculated from self-reported body weight and height with that calculated from measured values has been shown[28,29], which suggests that BMI calculated from self-reported body weight and height is a reliable measure, at least for use in correlation analysis. Furthermore, although we tried to adjust for a wide range of potential confounding factors, monetary cost of dietary energy might be a surrogate of factors associated with BMI which we did not measure in the present study (e.g. socio-economic level of families), as having or using money is unlikely directly related to BMI. Thus, the public health relevance of this finding is highly uncertain.

A number of methodological limitations of this study should be mentioned. First, in the absence of actual food expenditure data, food prices were derived from the National Retail Price Survey and websites of nationally distributed supermarket and fast-food restaurant chains. As this procedure gives only an approximation of actual diet costs, the results of the present study should be interpreted with caution. We note, however, that a similar methodology has been used in all previous observational studies[5–10].

Second, although we used a validated DHQ[13–15], the underreporting of dietary intake remains a serious concern[30]. To minimise the influence of dietary underreporting, we used energy-adjusted values. Studies have consistently shown that underreporting is more prevalent among people with higher BMI[30,31], and that energy-dense, nutrient-dilute and low-cost foods such as fat and oils, sugar and confectioneries are more likely to be selectively underreported[30,32]. However, as mentioned above, exclusion of energy underreporters identified by the Goldberg cut-off method[21,23] did not change the results materially, which may support the robustness of the findings in the present study.

Several intervention studies in the USA reported nutrient-dense diets that were not more expensive than lower-quality diets[33–35]. These intervention studies provided individual instruction on how to identify nutritious low-cost foods, how and where to make food purchases, and how to store and prepare the foods, possibly facilitating the consumption of a healthier diet at lower cost. However, the observational nature of the present study did not allow us to investigate directly the cost of dietary change following nutritional intervention.

Finally, because our subjects were selected female dietetic students, we may not be able to extrapolate our results to the general Japanese population. To minimise the influence of nutritional education, the present survey was conducted in most institutions within 2 weeks after the course began. As the subjects are likely to have a high level of nutrition knowledge and elevated rates of social desirability concerning diet, health and body weight, they are also likely to report lower body weights (and higher body heights) and lower energy intakes than average. However, mean values of BMI and energy intake in our subjects ($21.0\,\mathrm{kg\,m^{-2}}$ and $1822\,\mathrm{kcal\,day^{-1}}$, respectively) were highly comparable with those in a representative sample of Japanese women aged 15–19 years ($21.0\,\mathrm{kg\,m^{-2}}$ and $1858\,\mathrm{kcal\,day^{-1}}$, respectively)[12].

In conclusion, monetary cost of dietary energy was associated with not only favourable but also unfavourable aspects of dietary intake among a large group of young Japanese women. Additionally, monetary cost of dietary energy was inversely associated with BMI, although the magnitude was quite low. Because the relationship between dietary cost, nutrient and food intakes and BMI is an important public health topic, our observation in a selected population should be confirmed using more precise evaluation of diet costs or actual food expenditures in a more representative sample of the Japanese population.

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Authorship responsibilities: K.M. was involved in designing the study, data collection and data management, conducted the statistical analyses, and wrote the manuscript. S.S. was responsible for designing the study, data collection and data management, the overall management, and assisted in manuscript preparation. H.O. was involved in the study design. Y.T. assisted in the manuscript preparation. Y.H. was involved in study design, data collection and data management. M.I. was involved in data collection and data management. All of the authors provided suggestions during the preparation of the manuscript and approved the final version submitted for publication.

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Applied nutritional investigation

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

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Abstract

Objective: Little is known about the relation of dietary energy density (kilocalories per gram) to metabolic risk factors, particularly in young adults and non-Western populations. We examined the cross-sectional associations between dietary energy density and several metabolic risk factors in free-living young Japanese women.
Methods: The subjects were 1136 female Japanese dietetic students 18–22 y of age. Dietary energy density was estimated based on foods only, using a self-administered diet history questionnaire; before the present analysis, this measurement was validated against 16-d weighed dietary records in 92 Japanese women 31–69 y of age (Pearson's correlation coefficient 0.52). Body height and weight, from which body mass index (BMI) was derived, waist circumference, and blood pressure were measured, and fasting blood samples were collected for biochemical measurements.
Results: Mean BMI was 21.3 kg/m^2 (standard deviation 2.7), mean waist circumference was 72.9 cm (standard deviation 7.1), and mean dietary energy density was 1.41 kcal/g (standard deviation 0.23). After adjustment for potential confounding factors, dietary energy density was positively associated with BMI (*P* for trend = 0.004). Dietary energy density also showed an independent and positive association with waist circumference (*P* for trend <0.0001). No significant associations were observed between dietary energy density and any of the other metabolic risk factors examined.
Conclusion: Dietary energy density was independently and positively associated with BMI and waist circumference, but not with other metabolic risk factors, in free-living young Japanese women who are not only lean but whose dietary energy density is also low compared with Western populations.

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

Introduction

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

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

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

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

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

Materials and methods

The present study was based on a cross-sectional multicenter survey conducted from February to March 2006 and from January to March 2007 among female dietetic students from 15 institutions in Japan. All measurements at each institution were conducted according to the survey protocol. Briefly, staff at each institution explained an outline of the survey to potential subjects. Those who responded positively were then provided detailed written and oral explanations of the survey's general purpose and procedure. The protocol of the study was approved by the ethics committee of the National Institute of Health and Nutrition, and written informed consent was obtained from each subject and also from a parent for subjects <20 y of age. A total of 1176 Japanese women took part. For the present analysis, women 18–22 y of age were selected ($n = 1154$). We then excluded women not completing survey questionnaires ($n = 1$), those with extremely low or high reported energy intakes (<500 or >4000 kcal/d, $n = 2$), those currently receiving dietary counseling from a doctor or dietitian ($n = 13$), those with previously diagnosed diabetes, hypertension, or cardiovascular disease ($n = 1$), and those without measurement of body height and weight ($n = 2$). Additionally, women providing non-fasting blood samples ($n = 34$) and those with missing information on any of metabolic risk factors ($n = 16$) were excluded from the analyses of biochemical measurements. Some women fell into more than one exclusion category. The final sample sizes were 1136 for BMI, waist circumference, and systolic and diastolic blood pressures and 1087 for cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin.

Dietary habits during the preceding month were assessed using a validated, self-administered, comprehensive, diet history questionnaire (DHQ) [28–30]. Responses to the DHQ and those to an accompanying lifestyle questionnaire were checked at least twice for completeness. When necessary, forms were reviewed with the subject to ensure the clarity of answers. The DHQ is a 16-page structured questionnaire that consists of the following seven sections: general dietary behavior; major cooking methods; consumption frequency and amount of six alcoholic beverages; consumption frequency and semiquantitative portion size of 118 selected food and non-alcoholic beverage items; dietary supplements; consumption frequency and semiquantitative portion size of 19 cereals (rice, bread, and noodles), soup consumed with noodles, and miso (fermented soybean paste) soup; and open-ended items for foods consumed regularly (at least once per week) but not appearing in the DHQ [28]. The food and beverage items were selected as foods commonly consumed in Japan, mainly from a food list used in the National Nutrition Survey of Japan, and standard portions were derived mainly from several recipe books for Japanese dishes [28]. Estimates of dietary intake for a total of 150 food and beverage items (including five seasonings), energy, and selected nutrients were calculated using an ad hoc computer algorithm for the DHQ, which was based on the Standard Tables of Food Composition in Japan [26]. Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation of dietary intake [28]. Nutrient and food intakes were energy adjusted using the density method, i.e., percentage of energy for energy-providing nutrients and amounts per 1000 kcal of energy for other nutrients and foods. Detailed description of the validity of the DHQ with respect to commonly studied nutritional factors and the methods used to calculate dietary intake have been published elsewhere [28–30]. For example, Pearson's correlation coefficients between the DHQ and 3-d estimated dietary records were 0.48 for energy, 0.48 for protein, 0.55 for fat, and 0.48 for carbohydrate in 47 women [28].

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

Metabolic risk factors were measured 1–3 d after completion of the questionnaires. Body height was measured to the nearest 0.1 cm with the subject standing without shoes. Body weight in light indoor clothes was measured to the nearest 0.1 kg. BMI was calculated as body weight (kilograms) divided by the square of body height (meters). Waist circumference was measured at the level of the umbilicus to the nearest 0.1 cm. The measurement was taken at the end of a normal expiration while the subject was standing erect with her arms at her side and feet together. Systolic and diastolic blood pressures were measured on the left arm with an automatic device (Omron model HEM-770A, Omron Health Care, Kyoto, Japan) after the subject had been sitting quietly for $\geq$3 min. A second measurement was carried out about 1 min after the first, and the mean value of the two was used. Peripheral blood samples were obtained from subjects after an overnight fast. Blood was collected in evacuated tubes containing no additives, allowed to clot, and centrifuged at 3000*g* for 10 min at room temperature to separate the serum. Blood samples for glycated hemoglobin measurements were also collected in evacuated tubes containing no additives. In accordance with the survey protocol, blood samples were transported at −20°C by car or airplane to ensure delivery to a laboratory in Tokyo, Japan (SRL Inc. in 2006 and Mitsubishi Kagaku Bio-Clinical Laboratories Inc. in 2007). All biochemical variables used in the present study were assayed at the laboratory within 1–2 d of collection to avoid significant degradation. Serum total, LDL, and HDL cholesterol, triacylglycerol, and glucose concentrations were measured by enzymatic assay methods. Glycated hemoglobin was measured by latex agglutination-turbidimetric immunoassay. In-house quality-control procedures for all assays were conducted at the respective laboratory.

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

Dietary energy density was examined in relation to 10 metabolic risk factors, namely BMI, waist circumference, systolic and diastolic blood pressures, cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin. All statistical analyses were performed using SAS 8.2 (SAS Institute, Cary, NC, USA). Linear regression models were constructed using the PROC GLM procedure to examine the association between dietary energy density with metabolic risk factors. For the analyses, subjects were categorized into quartiles according to dietary energy density. The mean ± standard error metabolic risk factor values were calculated by quartiles of dietary energy density after multivariate adjustment for potential confounding factors. Confounding factors included residential block, size of residential area, survey year (2006 or 2007; because of the different laboratories used for blood analyses for the 2006 and 2007 surveys, even though there were no differences in the assay methods), current smoking, rate of eating, physical activity (continuous), and the ratio of total energy intake to estimated energy expenditure (continuous). BMI (continuous) was added as a confounding factor in all analyses except for that for BMI itself. Waist circumference (continuous) was also added as a confounding factor in the analyses except for those for BMI and waist circumference. Because the inclusion of measurements of obesity (BMI and/or waist circumference) as confounding factors did not influence the results materially, we present the full-adjustment models only. Linear trends with increasing levels of dietary energy density were tested for by assigning each participant a median value for the category and modeling this value as a continuous variable. All reported P values are two-tailed, and $P < 0.05$ was considered statistically significant.

Results

Basic characteristics of all subjects ($n = 1136$; those included in the analyses of BMI, waist circumference, and systolic and diastolic blood pressures) are presented in Table 1. Mean BMI was 21.3 kg/m^2, mean waist circumference was 72.9 cm, and mean dietary energy density was 1.41 kcal/g. The potential confounding variables for all subjects are listed in Table 2 according to quartile of dietary energy density. There was a positive association of dietary energy density with rate of eating and the ratio of total energy intake to estimated energy expenditure. Dietary energy density was also positively associated with BMI and waist circumference. The dietary intakes of all subjects are reported in Table 3 according to quartile of dietary energy density. Dietary energy density was associated positively with energy intake and negatively with amount of foods consumed. For nutrients, dietary energy density was associated positively with fat and negatively with water, dietary fiber, protein, and carbohydrate. For foods, dietary energy density was associated positively with bread, sugar and confectionaries, and fats and oils, and negatively with fruits and vegetables, noodles, rice, and meats and fish. According to the quartile of dietary energy density, similar patterns were observed for potential confounding factors and dietary intake among those subjects included in the analyses of cholesterol (total, HDL, and LDL), triacylglycerol, glucose, and glycated hemoglobin ($n = 1087$, data not shown). The multivariate-adjusted mean values for met-

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

Variable	
Age (y)	19.6 ± 1.1
Body height (cm)	158.4 ± 5.5
Body weight (kg)	53.6 ± 7.7
Body mass index (kg/m^2)	21.3 ± 2.7
Waist circumference (cm)	72.9 ± 7.1
Systolic blood pressure (mmHg)	106.4 ± 10.6
Diastolic blood pressure (mmHg)	69.3 ± 8.2
Total cholesterol (mg/dL)	189.1 ± 31.6
HDL cholesterol (mg/dL)	70.7 ± 12.7
LDL cholesterol (mg/dL)	107.1 ± 27.0
Triacylglycerol (mg/dL)	61.1 ± 28.8
Glucose (mg/dL)	84.1 ± 6.4
Glycated hemoglobin (%)	4.87 ± 0.26
Dietary energy density (kcal/g)†	1.41 ± 0.23

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

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

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

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

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

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

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

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

Discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

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

§ Also adjusted for body mass index (continuous).

‖ Also adjusted for waist circumference (continuous).

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

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

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

Conclusions

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

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Appendix

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

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