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Nutrition 25 (2009) 640–646

NUTRITION

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Applied nutritional investigation

Neighborhood food store availability in relation to food intake in young Japanese women

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Manuscript received November 4, 2008; accepted January 2, 2009.

Abstract

Objective: Information on the association between the local food environment and the diet of individuals is limited, particularly in settings with high population density and, hence, high food-store density, such as Japan. This cross-sectional study examined the association between neighborhood food-store availability and individual food intake in a group of young Japanese women.

Methods: Participants were 990 female Japanese dietetic students 18–22 y of age. Neighborhood food-store availability was defined as the number of food stores within a 1-km mesh-block of residence, derived from the census of commerce. Dietary intake was estimated using a validated, comprehensive self-administered diet-history questionnaire.

Results: After adjustment for potential confounding factors, including household socioeconomic status, geographic variables, and the frequency of eating out, neighborhood store availability for confectioneries and bread (based on confectionery stores/bakeries, supermarkets, and grocery and convenience stores) was significantly positively associated with the intake of confectioneries and bread. No significant independent association was seen between neighborhood store availability for the other foods examined, including meat (meat stores, supermarkets, and grocery stores), fish (fish stores, supermarkets, and grocery stores), fruit and vegetables (fruit/vegetable stores, supermarkets, and grocery stores), and rice (rice stores, supermarkets, and grocery and convenience stores) with intake of each food.

Conclusion: In a group of young Japanese women, increasing neighborhood store availability for confectioneries and bread was independently associated with higher intake of confectioneries and bread. In contrast, no association between availability and intake was seen for meat, fish, fruit and vegetables, or rice. © 2009 Published by Elsevier Inc.

Keywords: Neighborhood; Food-store availability; Food intake; Young women; Japan; Epidemiology

Introduction

Growing recognition of the importance of diet on health has been accompanied by increasing attention to factors associated with access to healthy foods. However, findings in the increasing, albeit still limited, number of studies examining associations between local food environments and resident diets have been inconsistent [1–7]. In a number of U.S. studies, the availability of a least one supermarket in census tracts was associated with a higher likelihood of meeting guidelines for fruit and vegetables and guidelines for total fat and saturated fat in adults who lived in these census tracts [1]; a shorter distance from home to a food store was associated with a greater use of fruit in low-income households [2]; proximity to a supermarket was associated with a better diet quality in pregnant women [3]; and participants with no supermarket near their homes were less likely to have a healthy diet than those with the most stores [4]. In a national study in New Zealand, conversely, access to supermarkets

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0899-9007/09/$ – see front matter © 2009 Published by Elsevier Inc.
doi:10.1016/j.nut.2009.01.002

was not associated with fruit and vegetable consumption, although better access to convenience stores was associated with a lower intake of vegetables, but not of fruit [5]. In addition, better access to food stores was not associated with consumption of fruit or vegetables in U.S. adults [6] or in a British population [7].

Except for the study in the United Kingdom, however, which has a population density of 244 persons/km^2, these previous studies were to our knowledge conducted in settings with a low population density and, hence, low food-store density, namely the United States and New Zealand (population densities 32 and 15 persons/km^2, respectively) [8]. Information is lacking for settings with a high population density and, hence, high food-store density, including Japan (population density 339 persons/km^2) [8]. In addition, most of these studies focused only on fruit and vegetable intake and gave little or no consideration to other food groups [1,2,5–7], and only a few used a validated dietary assessment instrument [1,3,4].

We speculated that several characteristics of the Japanese diet (e.g., high intake of rice) [9] and food store environment (e.g., high density of a wide variety of stores, including fresh-produce stores) [10] would provide insights into the influence of a local food environment on an individual diet. We conducted a cross-sectional study of the association between neighborhood food-store availability and food intake as assessed using a validated, comprehensive self-administered diet-history questionnaire (DHQ) [11–14] in a group of young Japanese women.

Materials and methods

Study sample

The present study was based on data from the Japan Dietetic Students' Study for Nutrition and Biomarkers, a cross-sectional multicenter survey conducted from February to March 2006 and from January to March 2007 in female dietetic students from 15 institutions in Japan. A total of 1176 Japanese women took part. A detailed description of the study design and survey procedure has been published elsewhere [15–17]. In the present study, 1-km mesh-blocks (approximately a 1- × 1-km square) were used as approximations of neighborhoods. Using their home addresses as reported in the lifestyle questionnaire, study participants were geocoded to 1-km mesh-blocks by exact address matching.

For the present analysis, we selected women 18–22 y of age (n = 1154). We then excluded women not providing sufficient information on their home addresses (n = 163), those who reported extremely low or high energy intakes (<500 or >4000 kcal/d, n = 3), and those with missing information on the variables used (n = 1). Because some participants were in more than one exclusion category, the final analysis sample comprised 990 women who resided in 704 neighborhoods (i.e., 1-km mesh-blocks).

This study was approved by the ethics committee of the National Institute of Health and Nutrition, Japan. Written informed consent was obtained from each participant and from a parent for participants younger than 20 y.

Neighborhood food-store availability

Neighborhood food-store availability was characterized by the number of stores offering foods in the neighborhood (i.e., 1-km mesh-block) in which a participant lived. Data on the number of food stores within the 1-km mesh-blocks were derived from the census of commerce of 2002 [10], which included data on supermarkets, grocery stores, meat stores, fish stores, fruit/vegetable stores, confectionery stores/bakeries, rice stores, and convenience stores (but not dining establishments). Confectionery stores and bakeries were combined in this census, mainly because of the widespread availability in Japan of various breads with sweet fillings (e.g., sweetened *azuki* bean paste), and bakeries commonly offer not only bread but also confectioneries such as cakes, cookies, and biscuits.

In Japan, supermarkets and grocery stores generally provide a wide range of food options including fresh produce, whereas convenience stores generally offer a variety of processed foods such as confectioneries and ready-to-eat meals including rice bowls and sandwiches with a limited amount of meat, fish, fruit, and vegetables as ingredients. Based on this, neighborhood store availability for each food was defined as follows: for meat, the sum of the number of meat stores, supermarkets, and grocery stores; for fish, the sum of the number of fish stores, supermarkets, and grocery stores; for fruit and vegetables, the sum of the number of fruit/vegetable stores, supermarkets, and grocery stores; for confectioneries and bread, the sum of the number of confectionery stores/bakeries, supermarkets, grocery stores, and convenience stores; and for rice, the sum of the number of rice stores, supermarkets, grocery stores, and convenience stores.

Food intake

Dietary habits during the preceding month were assessed using a comprehensive self-administered DHQ. Details of the DHQ's structure, calculation of dietary intake, and validity for commonly studied nutritional factors have been published elsewhere [11–14]. Briefly, the DHQ is a structured 16-page questionnaire that asks about the consumption frequency and portion size of selected foods commonly consumed in Japan, general dietary behavior, and usual cooking methods [11]. Estimates of daily intake for foods (150 items in total) and energy were calculated using an ad hoc computer algorithm for the DHQ [11,12] based on the standard tables of food composition in Japan [18].

In accordance with the data for neighborhood food-store availability, the following five food groups were considered: meat, fish, fruit and vegetables, confectioneries and bread, and rice (categorization of food groups has been published elsewhere [19]). To minimize the influence of dietary misreporting, an ongoing controversy in studies that collect dietary information using self-report instruments [20], the intake of each food group was adjusted by energy using the density method (grams per 1000 kcal). In a previous study of 92 women 31–69 y of age, Pearson's correlation coefficients between the DHQ and 16-d weighed dietary records were 0.66 for meat, 0.55 for fish and shellfish, 0.51 for fruit and vegetables, 0.51 for confectioneries and bread, and 0.64 for rice (S. Sasaki, unpublished observations, 2006), suggesting satisfactory validity of the DHQ in terms of these food groups.

Other variables

Based on the reported home address, each participant was grouped into one of six regions (Hokkaido and Tohoku, Kanto, Hokuriku and Tokai, Kinki, Chugoku and Shikoku, and Kyushu) and into one of three municipality levels (ward, city, and town and village). The participant was also grouped into one of four institution types (4-y private, 2-y private, 4-y public, and 2-y public) based on the institution she attended and into one of three living statuses (living with family, living alone, and living with others) as self-reported in the lifestyle questionnaire. Frequency of eating out (including school cafeteria) was self-reported as part of the DHQ (at least once per day, four to six times per week, two to three times per week, once per week, and less than once per week). Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, while wearing light clothes and no shoes. Body mass index was calculated as body weight (kilograms) divided by the square of body height (meters).

Statistical analysis

All statistical analyses were performed using SAS 9.1 (SAS Institute, Cary, NC, USA). For each of the five foods examined, linear regression models were constructed to examine the association of neighborhood food-store availability with food intake, using the PROC GLM procedure. For analyses, participants were categorized into approximate quartiles according to neighborhood store availability for each food. Multivariate adjusted mean values (with 95% confidence interval) of intake of each food were calculated by approximate quartile of neighborhood store availability for each food. Three models were constructed with a range of potential confounding factors. In model 1, the association was examined with adjustment for survey year (2006 and 2007). In model 2, household socioeconomic variables, i.e., institution type [21] and living status [19], and frequency of eating out were also included. In model 3, geographical variables, i.e., region and municipality level, were also included. We tested for linear trends with increasing levels of neighborhood food-store availability by assigning each participant the median value for the category and modeling this value as a continuous variable. All reported P values are two-tailed, and $P < 0.05$ was considered statistically significant. Because 90% of neighborhoods (i.e., 1-km mesh-blocks) had only one study participant, and only 3% had five or more participants, no special methods were needed to account for within-neighborhood correlations in outcomes.

Table 1
Participant characteristics (n = 990)*

Variable	
Age (y)	19.6 ± 1.0
Body height (cm)	158.2 ± 5.5
Body weight (kg)	53.6 ± 7.8
Body mass index (kg/m^2)	21.4 ± 2.8
Region	
Hokkaido and Tohoku	2.5
Kanto	56.1
Hokuriku and Tokai	10.8
Kinki	11.4
Chugoku and Shikoku	2.9
Kyushu	16.3
Municipality level	
Ward	17.3
City	76.3
Town and village	6.5
Survey year	
2006	41.6
2007	58.4
Institution type	
4-y private	70.8
2-y private	6.0
4-y public	14.2
2-y public	9.0
Living status	
Living with family	64.7
Living alone	32.1
Living with others	3.2
Frequency of eating out	
≥1 time/d	9.4
4–6 times/wk	21.0
2–3 times/wk	29.3
1 time/wk	19.7
<1 time/wk	20.6
Food intake (g/1000 kcal)	
Meat	33.8 ± 16.8
Fish	28.5 ± 15.1
Fruit and vegetables	180.6 ± 93.5
Confectioneries and bread	69.3 ± 32.1
Rice	156.6 ± 63.7
Neighborhood food store availability (number of food stores within 1-km mesh-block of residence)	
Meat	2.29 ± 2.48
Fish	2.31 ± 2.45
Fruit and vegetables	3.17 ± 3.51
Confectioneries and bread	8.70 ± 8.64
Rice	5.15 ± 5.34

* Values are means ± SDs or percentages of participants.

Results

Characteristics of participants are listed in Table 1. As expected, neighborhood store availability for the five foods examined was highly correlated (Pearson's correlation coefficients 0.82–0.94). Potential confounding factors according to approximate quartile category of neighborhood store availability for confectioneries and bread (as an example) are listed in Table 2. Neighborhood store availability for confectioneries and bread was associated with region, municipality level, institution type, and living status. The higher quartiles of neighborhood store availability for confectioneries and bread (higher availability) included more participants living in Kanto and fewer participants living in Hokuriku and Tokai and Kyushu; more participants living in wards and fewer living in cities and towns and villages; more participants attending 4-y private institutions and fewer attending 2-y private and 4-y public institutions; and more participants living alone and fewer living with family. No association was seen for survey year or frequency of eating out. According to approximate quartile category of neighborhood store availability for other foods, namely meat, fish, fruit and vegetables, and rice, similar patterns were observed for potential confounding factors (data not shown).

Food intake according to approximate quartile category of neighborhood store availability for each food is presented in Table 3. No association between intake and neighborhood food-store availability was seen for meat, fish, or fruit and vegetables, regardless of adjustment for potential confounding factors. However, increasing neighborhood store availability for confectioneries and bread was significantly associated with higher intakes of these items after adjustment for survey year. This significant positive association remained after further adjustment for not only household socioeconomic variables (institution type and living status) and frequency of eating out but also geographic variables (region and municipality level). Conversely, increasing neighborhood store availability for rice was significantly associated with lower intakes of rice after adjustment for

Table 2
Geographical and household socioeconomic status characteristics and frequency of eating out according to approximate quartile category of neighborhood store availability for confectioneries and bread (n = 990)*

Variable	Quartile 1 (n = 280)	Quartile 2 (n = 245)	Quartile 3 (n = 218)	Quartile 4 (n = 247)	P†
Region					<0.0001
Hokkaido and Tohoku	2.1	3.7	3.7	0.8	
Kanto	38.6	55.5	56.9	75.7	
Hokuriku and Tokai	16.4	12.7	8.3	4.9	
Kinki	13.9	4.5	15.6	11.7	
Chugoku and Shikoku	3.6	3.3	5.1	0	
Kyushu	25.4	20.4	10.6	6.9	
Municipality level					<0.0001
Ward	3.9	13.5	18.4	35.2	
City	82.9	80.0	77.1	64.4	
Town and village	13.2	6.5	4.6	0.4	
Survey year					0.80
2006	40.7	41.6	39.9	44.1	
2007	59.3	58.4	60.1	55.9	
Institution type					<0.0001
4-y private	60.4	70.6	70.2	83.4	
2-y private	12.9	6.5	1.8	1.2	
4-y public	17.5	14.3	14.7	10.1	
2-y public	9.3	8.6	13.3	5.3	
Living status					<0.0001
Living with family	78.9	59.2	70.6	48.6	
Living alone	18.2	38.8	26.2	46.6	
Living with others	2.9	2.0	3.2	4.9	
Frequency of eating out					0.17
≥1 time/d	6.8	10.6	8.7	11.7	
4–6 times/wk	17.9	19.2	26.6	21.5	
2–3 times/wk	29.3	33.1	28.4	26.3	
1 time/wk	22.1	20.4	16.5	19.0	
<1 time/wk	23.9	16.7	19.7	21.5	

* Values are percentages of participants. According to approximate quartile category of neighborhood store availability for other foods including meat, fish, fruit and vegetables, and rice, similar patterns were observed.
† Chi-square test.

survey year and household socioeconomic variables. However, this association disappeared after further adjustment for geographic variables.

Discussion

In this cross-sectional study of a group of young Japanese women, we found that neighborhood store availability for confectioneries and bread was independently and positively associated with dietary intake of these items. Conversely, no independent association between availability and dietary intake was observed for meat, fish, fruit and vegetables, or rice. To our knowledge, this is the first study to investigate the association between neighborhood food-store availability and dietary intake regarding a variety of foods in a setting with a high population density and, hence, a high density of food stores.

Our finding that local food environment is associated with at least some aspects of a resident's diet is consistent with several previous studies [1–5]. Our present association of neighborhood food-store availability with the intake of confectioneries and bread only, and not with that of other foods, including meat, fish, fruit and vegetables, or rice, is reasonable, considering that confectioneries and bread are generally ready to eat, whereas most other foods require a degree of preparation (e.g., cooking and peeling). The inverse association between neighborhood store availability for rice and rice intake observed before adjustment for geographic variables may be due to regional differences in rice intake consistently observed in Japan (in particular, a high intake in Kyushu and a low intake in Kanto) [9].

Table 3
Food intake (grams per 1000 kcal) according to approximate quartile category of neighborhood food store availability (number of food stores within a 1-km mesh-block of residence; n = 990)*

Variable	Quartile 1	Quartile 2	Quartile 3	Quartile 4	$P^{\dagger}$
Neighborhood store availability for meat	0 (0)	1 (1)	3 (2–3)	5 (4–17)	
n	255	212	319	204	
Meat intake					
Model 1‡	35.0 (33.0–37.1)	33.7 (31.4–35.9)	31.4 (29.5–33.2)	36.1 (33.8–38.4)	0.95
Model 2§	34.6 (32.6–36.6)	34.0 (31.8–36.2)	32.4 (30.6–34.2)	34.7 (32.4–36.9)	0.68
Model 3‖	34.1 (32.0–36.2)	34.5 (32.3–36.7)	32.7 (30.9–34.5)	34.4 (32.0–36.8)	0.75
Neighborhood store availability for fish	0 (0)	1 (1)	2 (2–3)	4 (4–20)	
n	254	230	231	275	
Fish intake					
Model 1‡	26.2 (24.3–28.0)	29.0 (27.1–30.9)	32.1 (30.1–34.0)	27.4 (25.6–29.1)	0.53
Model 2§	25.6 (23.8–27.4)	29.4 (27.6–31.3)	31.0 (29.2–32.8)	28.4 (26.7–30.1)	0.09
Model 3‖	25.5 (23.6–27.3)	29.5 (27.6–31.4)	30.9 (29.0–32.7)	28.6 (26.8–30.3)	0.08
Neighborhood store availability for fruit and vegetables	0 (0)	1 (1)	3 (2–5)	6 (6–25)	
n	222	199	337	232	
Fruit and vegetable intake					
Model 1‡	180.7 (168.4–193.0)	191.0 (178.0–203.9)	182.4 (172.5–192.4)	169.2 (157.1–181.2)	0.06
Model 2§	177.7 (165.3–190.2)	194.0 (181.1–206.9)	180.0 (170.0–189.9)	172.9 (160.8–185.1)	0.16
Model 3‖	175.4 (162.5–188.4)	195.1 (182.0–208.1)	180.0 (170.0–189.9)	174.3 (161.4–187.2)	0.27
Neighborhood store availability for confectioneries and bread	1 (0–2)	5 (3–6)	9 (7–13)	17 (14–55)	
n	280	245	218	247	
Confectionery and bread intake					
Model 1‡	64.1 (60.4–67.8)	68.7 (64.7–72.7)	69.6 (65.4–73.8)	75.5 (71.5–79.5)	<0.0001
Model 2§	66.1 (62.3–69.8)	67.7 (63.8–71.6)	69.7 (65.6–73.9)	74.1 (70.2–78.1)	0.003
Model 3‖	66.9 (63.0–70.8)	68.2 (64.3–72.1)	69.1 (64.9–73.2)	73.2 (69.0–77.5)	0.04
Neighborhood store availability for rice	1 (0–1)	2 (2–3)	6 (4–7)	12 (8–38)	
n	283	193	323	191	
Rice intake					
Model 1‡	166.5 (159.1–173.8)	159.3 (150.4–168.1)	151.3 (144.4–158.1)	148.1 (139.2–157.0)	0.001
Model 2§	163.1 (155.8–170.5)	160.4 (151.7–169.1)	153.2 (146.5–160.0)	148.5 (139.7–157.4)	0.007
Model 3‖	158.5 (150.8–166.2)	160.9 (152.2–169.6)	155.7 (148.8–162.5)	150.8 (140.9–160.7)	0.16

* Values are medians (ranges) for neighborhood food store availability or means (95% confidence intervals) for food intake.

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

‡ Adjusted for survey year (2006 and 2007).

§ Adjusted for survey year, institution type (4-y private, 2-y private, 4-y public, and 2-y public), living status (living with family, living alone, and living with others), and frequency of eating out (at least once per day, four to six times per week, two to three times per week, once per week, and less than once per week).

‖ Adjusted for survey year, institution type, living status, frequency of eating out, region (Hokkaido and Tohoku; Kanto; Hokuriku and Tokai; Kinki; Chugoku and Shikoku; and Kyushu), and municipality level (ward; city; and town and village).

However, our results are based on a highly selected population and thus are not likely to extrapolate to the general Japanese population. The participants were selected female dietetic students, and owing to the recruitment procedure used, the response rate could not be precisely determined, although the approximate rate was 56%. These elements of the design may have produced recruitment bias. As such the participants likely had a higher education level and a greater knowledge of diet and nutrition than the general population. Given the finding of an association in this population, in which education and nutritional knowledge likely had a greater influence on food choice than the local food environment, associations between availability and intake might be expected to be stronger in the general Japanese population.

Several limitations of the present study deserve mention. First, the cross-sectional nature of the study hampers the drawing of any conclusions on causal inferences between neighborhood food-store availability and food intake. Second, we did not have information on where participants actually shopped for food. As such our exposure variable is only a proxy for the neighborhood food environment. Third, we used an arbitrary unit (i.e., 1-km mesh-block) as approximations of neighborhoods, but these units may not represent the area of actual relevance to the food-shopping habits of a particular individual. For example, reliance on the neighborhood environment for food may differ by other factors such as transportation use, information that was not available in the present study. Fourth, the number and type of stores used as proxies for the availability of several foods may be a limitation; more specific information regarding the types and costs of foods sold at these establishments may have been useful. Fifth, because data for food stores (2002) and dietary intake (2006 and 2007) were collected at different times, the present study had to be based on the assumption that the food environment remained constant from 2002 to 2007. Sixth, we were unable to control for other factors that may influence individual dietary choices, and these may also be associated with the neighborhood food environment (e.g., personal food preferences).

Conclusion

In young Japanese women, increasing neighborhood store availability for confectioneries and bread was independently associated with a higher intake of these items, whereas no such association was seen for meat, fish, fruit and vegetables, or rice. Because of the cross-sectional design, any firm conclusions on this issue require additional studies.

Acknowledgments

The authors thank Keika Mine, Yoko Hosoi, Mami Itabashi, Tomono Yahata, Asako Ishiwaki, and Kyoko Saito (National Institute of Health and Nutrition) for data collection.

Appendix

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Public Health Nutrition: 12(8), 1290–1297 doi:10.1017/S1368980008003923

Monetary cost of self-reported diet in relation to biomarker-based estimates of nutrient intake in young Japanese women

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Submitted 7 May 2008: Accepted 15 September 2008: First published online 14 November 2008

Abstract

Objective: All previous studies on monetary diet cost have examined the relationship of monetary cost of self-reported diet to self-reported, rather than biomarker-based, estimates of dietary intake. The present cross-sectional study examined the association between monetary costs of self-reported diet and biomarker-based estimates of nutrient intake.

Design: Monetary diet cost (Japanese yen/1000 kJ) was calculated based on dietary intake information from a self-administered, comprehensive diet history questionnaire using retail food prices. Biomarker-based estimates of nutrient intake (percentage of energy for protein and mg/1000 kJ for K and Na) were estimated based on 24 h urinary excretion and estimated energy expenditure.

Setting: A total of fifteen universities and colleges in Japan.

Subjects: A total of 1046 female Japanese dietetic students aged 18–22 years.

Results: Total monetary diet cost showed a significant positive association with biomarker-based estimates of protein, K and Na. Vegetables and fish were not only the main contributors to total monetary diet cost (16·4 % and 15·5 %, respectively) but also were relatively strongly correlated with total monetary diet cost (Pearson's correlation coefficient: 0·70 and 0·68, respectively). Monetary cost of vegetables was significantly positively associated with all three nutrients, while that of fish showed a significant and positive association only with protein.

Conclusions: Total monetary cost of self-reported diet was positively associated with biomarker-based estimates of protein, K and Na intake in young Japanese women, and appeared mainly to be explained by the monetary costs of vegetables and fish.

Keywords
Monetary diet cost
24 h urine
Epidemiology

While food choice is influenced by a large number of factors[1], the price of food is clearly an important determinant[2,3]. Generally, energy-dense and nutrient-dilute foods such as cereals, fats and oils, and sugar and sweets provide dietary energy at lowest cost. Conversely, the cost per kilojoule of energy-dilute and nutrient-dense foods, including vegetables, fish and fruit, is much higher. If healthier foods cost more then so too will healthier diets. In fact, several[4–9] although not all[10] observational studies have shown that healthful diets are more expensive than less healthful diets.

However, all of these previous studies have estimated both monetary diet costs and dietary intake based on self-reported dietary intake obtained by the same dietary assessment method, resulting in an inevitable over-estimation of the association between monetary diet cost and dietary intake due to errors shared by monetary diet costs and dietary intake. Given the difficulty in estimating

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monetary diet cost at the individual level without dietary intake information[11] as well as the existence of valid biomarkers for dietary intake of several nutrients[12–16], the combined use of monetary diet cost estimated from self-reported dietary intake information and biomarker-based estimates of dietary intake is an attractive alternative methodology for this important public health issue.

The Japan Dietetic Students' Study for Nutrition and Biomarkers[17–19] is unique in that both estimates of monetary cost of self-reported diet and urine biomarker-based estimates of dietary intake are available (although blood biomarkers of dietary intake are unfortunately unavailable due to limited financial resources). In the current preliminary report, we used this data set to investigate the association of monetary diet cost[10] estimated from a self-administered, comprehensive diet history questionnaire (DHQ)[20–23] with biomarker-based estimates of dietary protein[12,13], K[14,15] and Na[14,16] obtained from 24 h urinary excretion.

Subjects and methods

Subjects

The present study was based on a cross-sectional multi-centre survey conducted from February to March 2006 and from January to March 2007 among female dietetic students from fifteen institutions in Japan. Detailed descriptions of the survey have been published elsewhere[17–19]. Briefly, staff at each institution provided an outline of the survey to potential subjects. Those who agreed to participate were then provided detailed written and oral explanations of the survey's general purpose and procedure. A total of 1176 Japanese women took part. All measurements at each institution were conducted according to the survey protocol. The study protocol was approved by the Ethics Committee of the National Institute of Health and Nutrition, Japan. Written informed consent was obtained from each subject, and also from a parent for subjects aged <20 years.

Monetary diet cost

Dietary habits during the preceding month were assessed using a self-administered, comprehensive DHQ. Detailed descriptions of the DHQ concerning its structure, calculation of dietary intake and validity for commonly studied nutritional factors have been published elsewhere[20–23]. Responses to the DHQ were checked at least twice for completeness by trained survey staff (mostly registered dietitians) and, when necessary, forms were reviewed with the subject to ensure the clarity of answers. Briefly, the DHQ is a 16-page structured questionnaire which asks about the consumption frequency and portion size of selected foods commonly consumed in Japan as well as general dietary behaviour and usual cooking methods[20]. Estimates of daily intake for foods (150 items in total) and energy were calculated using an *ad hoc* computer algorithm for the DHQ[20,23], which was based on the *Standard Tables of Food Composition in Japan*[24].

Monetary cost of the habitual diet (Japanese yen/d) was calculated by multiplying the amount of each food estimated from the DHQ (g/d) by the estimated price of the food (Japanese yen/g) and summing the products (1 Japanese yen = 0·0048 GBP = 0·0062 € = 0·0095 $US in May 2008). A detailed description of the cost calculation method as well as the monetary cost of each food has been published elsewhere[10]. Briefly, the price of each food was determined based on the National Retail Price Survey 2004[25]. For foods whose price was not published in the survey (thirteen items), prices were taken from the websites of a nationally distributed supermarket (Seiyu, Tokyo, Japan) or fast-food restaurant (McDonalds, Tokyo, Japan and Mister Donut, Tokyo, Japan) chain. Alcoholic beverages (six items), non-caloric beverages (four items) and water (three items) were excluded from calculation[4]. Costs of combined foods such as pizza were calculated using the prices of frozen equivalents[9]. The procedure for estimating costs was based on the assumption that all foods were purchased and then prepared and consumed at home[11].

While the misreporting of dietary intake, a serious problem associated with self-report dietary assessment methods, is strongly associated with BMI not only in Western populations with relatively high mean BMI[26] but also in Japanese populations with relatively low mean BMI[17], BMI-dependent misreporting seems to be cancelled by energy adjustment, at least for protein, K and Na[17]. Energy-adjusted values of total monetary diet cost as well as the monetary cost of selected food groups (Japanese yen/1000 kJ) were thus calculated by dividing the estimated monetary cost (Japanese yen/d) by the total energy intake (kJ/d) and multiplying by 1000. Categorization of food groups has been published elsewhere[10].

Biomarker-based estimate of nutrient intake

Within 1–3 d after completion of the questionnaires, a single 24 h urine collection was performed. Detailed descriptions of the procedure of 24 h urine collection have been published elsewhere[17,19]. Briefly, subjects were provided with three or four 1-litre bottles (containing no additives), ten 400 ml cups marked with 50 ml lines on both the inner and outer surfaces (to facilitate urine collection and missing urine estimation) and a recording sheet, and were asked to collect all urine specimens during a 24 h period in the bottles (using the cups) as well as to record on the sheet the time of the start and end of the collection period (start usually 06.00–09.00 hours) and the estimated volume of all missing urine specimens. The recording sheet was reviewed by the staff when the collection bottles were handed in, and any missing information was obtained from subjects. In the 2006 survey, the height of urine in each bottle was measured and later converted into volume with an empirical formula based on repeated measurements of volume in identical bottles, as described in a previous study[27]; in the 2007 survey, the total urine volume was directly measured using a graduated cylinder. We adjusted 24 h urine volume by self-reported collection time (calculated from the self-reported time of the start and end of the collection period) and missing urine volume; the utility of this adjustment has been indicated, at least in well-motivated populations[19].

All urine samples taken over the 24 h period were carefully mixed, and several aliquots were taken and transported at −20°C by car or aeroplane to ensure delivery to a laboratory (SRL Inc., Tokyo, Japan in 2006 and Mitsubishi Kagaku Bio-Clinical Laboratories Inc., Tokyo, Japan 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. Urea-N concentrations were measured using the enzymatic assay method, K and Na using the electrode method, and creatinine (for the assessment for completeness of urine collection) using the enzymatic assay method. In-house quality control procedures for all assays were conducted at the respective laboratory. Total 24 h excretion was calculated by multiplying the measured concentration by the (adjusted) volume of 24 h urine. Urea-N content in 24 h urine was multiplied by 9·08, assuming that urea-N is in constant proportion (85 %) to total urinary N[12], 81 % of ingested N is excreted through the urine[12,13] and N constitutes 16 % of protein. K content in 24 h urine was divided by 0·77, assuming that 77 % of ingested K is excreted through the urine[14,15]. Na content in 24 h urine was divided by 0·86, assuming that 86 % of ingested Na is excreted through the urine[14,16].

On the day the collected 24 h urine sample was handed in, body height and weight were measured to the nearest 0·1 cm and 0·1 kg, respectively, while the subject was wearing light clothes and no shoes. BMI was calculated as body weight (kg) divided by the square of body height (m). Energy expenditure can be estimated as BMR multiplied by an appropriate physical activity level value[28]. BMR was estimated using measured body weight according to the FAO/WHO/United Nations University equation for women aged 18–30 years[29]. In the absence of an accurate and comprehensive measure 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 (mean: 16·44, 0·06, 0·25 and 0·45 h/d, respectively) indicating a predominantly sedentary lifestyle, as described previously[18]. We thus estimated energy expenditure as estimated BMR by physical activity level value for light activity (1·56)[29]. Considering the influence of body size (and physical activity) on the amount of food consumed and hence urinary excretion of nutrients, energy-adjusted values of biomarker-based estimates of nutrient intake (percentage of energy for protein and mg/1000 kJ for K and Na) were calculated using 24 h urinary excretion (with conversion for intake estimation, as described above) and estimated energy expenditure[17,30].

Statistical analysis

All statistical analyses were performed with the SAS statistical software package version 8·2 (SAS Institute Inc., Cary, NC, USA). Using the PROC GLM procedure, linear regression models were constructed to examine the association of monetary cost of the self-reported diet (total and selected food groups) with biomarker-based estimates of nutrient intake (protein, K and Na). For analyses, subjects were categorized into quintiles according to monetary cost of the self-reported diet. Mean values (with 95 % confidence intervals) of biomarker-based estimates of nutrient intake were calculated by quintile of monetary cost of the self-reported diet. Adjustment was made for survey year (2006 or 2007) because of the differences in the procedure used to measure 24 h urine volume and in the laboratory used for biochemical measurements. For analysis of the monetary costs of individual food groups, adjustment was also made for the monetary costs of all other food groups (continuous). We tested for linear trends with increasing levels of monetary cost of self-reported diet by assigning each participant the median value for the category and modelling this value as a continuous variable. We also calculated the regression coefficient (and 95 % confidence interval) expressing changes of biomarker-based estimates of nutrient intake for an increment of monetary costs of 1 Japanese yen/1000 kJ of self-reported diet by multiple regression analysis (using the PROC REG procedure). All reported P values are two-tailed and $P < 0.05$ was considered significant.

Results

In total, 1105 of 1176 women undertook 24 h urine collection. For the present analysis, women aged 18–22 years were selected (n 1083). We then excluded women not completing survey questionnaires (n 1) and those with extremely low or high reported energy intakes (<2092 or >16 736 kJ/d; n 1). We further excluded those whose 24 h urine collection was considered incomplete (n 35) as assessed using information on urinary creatinine excretion and body weight based on a strategy proposed by Knuiman *et al.*[31] and as per our previous analysis[19], which showed that only thirty-six (5·5 %) of 654 Japanese female dietetic students were identified as having incomplete 24 h urine by the *p*-aminobenzoic acid check method and that this creatinine-based strategy was useful (sensitivity: 0·47; specificity: 0·99), at least in well-motivated populations where the proportion of incomplete urine is presumed to be small. The final analysis sample comprised 1046 women.

Basic characteristics of the subjects are shown in Table 1. Important contributors to total monetary diet cost were vegetables, fish, meat and confectioneries, followed by rice, dairy products and fruits. Pearson's correlation matrix of monetary costs of self-reported diet is shown in Table 2. Total monetary cost of self-reported diet was correlated relatively strongly with the monetary costs of vegetables and fish; modestly with those of meat, rice and fruits; and somewhat weakly with those of confectioneries and dairy products. Correlations among the monetary costs of food groups were low to modest.

Associations between monetary cost of self-reported diet and biomarker-based estimates of nutrient intake are shown in Table 3. Similar results were observed when monetary cost of self-reported diet was treated as a categorical variable (quintile) and as a continuous variable. Total monetary cost of self-reported diet was significantly positively associated with biomarker-based estimates of protein, K and Na intake. The monetary cost of vegetables was also significantly positively associated with all three nutrients, while the monetary cost of fish showed a significant and positive association with protein but not with K or Na. Regarding the monetary costs of other foods, there were significant negative associations between the monetary cost of confectioneries and Na and between that of fruits and protein and Na, and significant positive associations between that of dairy products and protein and K.

Discussion

In the current preliminary study of young Japanese women, we found that total monetary cost of self-reported diet was positively associated with biomarker-based estimates of protein, K and Na intake. To our knowledge, the present study is the first to examine the relationship of monetary costs of the self-reported diet with biomarker-based, rather than self-reported, estimates of dietary intake.

A limited number of observational studies in Europe have consistently shown that healthful diets are more

Table 1 Basic characteristics of 1046 Japanese women aged 18–22 years: subset of participants in the Japan Dietetic Students' Study for Nutrition and Biomarkers, 2006 and 2007

Variable	Mean or %	SD
Age (years)	19·6	1·0
Body height (cm)	158·4	5·4
Body weight (kg)	53·3	7·3
BMI (kg/m^2)	21·2	2·5
Survey year (%)		
2006	38·9	
2007	61·1	
Biomarker-based estimates of nutrient intake		
Protein (% of energy)	13·8	3·4
K (mg/1000 kJ)	271	98
Na (mg/1000 kJ)	462	173
Monetary costs of self-reported diet (Japanese yen*/1000 kJ)		
Total	107·6	18·2
Vegetables	17·7	10·2
Fish	16·7	8·8
Meat	16·6	8·5
Confectioneries	12·9	6·8
Rice	9·3	3·7
Dairy products	8·7	5·2
Fruits	5·8	4·9

*1 Japanese yen = 0·0048 GBP = 0·0062 € = 0·0095 $US in May 2008.

Table 2 Pearson's correlation matrix of monetary costs of self-reported diet (Japanese yen*/1000 kJ) in 1046 Japanese women aged 18–22 years: subset of participants in the Japan Dietetic Students' Study for Nutrition and Biomarkers, 2006 and 2007

	Total	Vegetables	Fish	Meat	Confectioneries	Rice	Dairy products	Fruits
Total	–	0·70	0·68	0·38	0·08	−0·35	0·05	0·40
Vegetables		–	0·35	0·04	−0·13	−0·07	−0·06	0·21
Fish			–	0·18	−0·14	−0·06	−0·09	0·14
Meat				–	−0·16	−0·07	−0·24	−0·07
Confectioneries					–	−0·41	0·00	−0·03
Rice						–	−0·31	−0·12
Dairy products							–	0·07
Fruits								–

*1 Japanese yen = 0·0048 GBP = 0·0062 € = 0·0095 $US in May 2008.

Table 3 Biomarker-based estimates of nutrient intake according to quintile (Q) of monetary cost of self-reported diet in 1046 Japanese women aged 18–22 years*: subset of participants in the Japan Dietetic Students' Study for Nutrition and Biomarkers, 2006 and 2007

	Biomarker-based estimates of nutrient intake					
	Protein (% of energy)		K (mg/1000 kJ)		Na (mg/1000 kJ)	
Monetary costs of self-reported diet (Japanese yen†/1000 kJ)	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
Total						
Q1 [85·8]‡	13·3	12·9, 13·7	238	225, 251	426	403, 450
Q2 [97·1]	13·5	13·1, 13·9	262	249, 275	468	445, 492
Q3 [106·9]	14·0	13·6, 14·4	284	271, 297	475	452, 498
Q4 [115·6]	13·8	13·4, 14·2	269	256, 282	468	445, 491
Q5 [131·4]	14·4	14·0, 14·8	301	288, 314	475	451, 498
P for trend§	0·0005		<0·0001		0·011	
Regression coefficient (95 % CI)‖	0·005	0·002, 0·008	0·99	0·68, 1·30	0·71	0·15, 1·27
P	0·0002		<0·0001		0·013	
Vegetables						
Q1 [7·7]	13·6	13·2, 14·0	236	222, 249	435	411, 459
Q2 [11·6]	13·6	13·2, 14·0	258	245, 271	451	428, 475
Q3 [15·6]	13·9	13·5, 14·3	267	255, 280	465	442, 488
Q4 [20·6]	13·7	13·3, 14·1	286	273, 298	471	448, 495
Q5 [30·2]	14·3	13·9, 14·7	308	294, 321	491	467, 515
P for trend	0·032		<0·0001		0·002	
Regression coefficient (95 % CI)	0·008	0·003, 0·013	2·50	1·91, 3·08	2·05	0·97, 3·13
P	0·002		<0·0001		0·0002	
Fish						
Q1 [6·6]	13·3	12·9, 13·7	273	260, 287	446	422, 469
Q2 [11·6]	13·5	13·1, 13·9	263	250, 276	450	427, 473
Q3 [15·6]	13·8	13·4, 14·2	272	260, 285	489	466, 511
Q4 [19·9]	14·1	13·7, 14·5	276	263, 289	481	458, 504
Q5 [28·2]	14·3	13·9, 14·7	269	256, 282	448	424, 472
P for trend	0·002		0·98		0·74	
Regression coefficient (95 % CI)	0·009	0·003, 0·015	−0·11	−0·79, 0·58	0·20	−1·04, 1·45
P	0·002		0·76		0·74	
Meat						
Q1 [7·5]	13·8	13·4, 14·2	275	262, 288	455	431, 479
Q2 [11·8]	13·7	13·3, 14·1	271	259, 284	449	426, 472
Q3 [15·2]	13·7	13·3, 14·1	261	248, 274	456	433, 479
Q4 [19·4]	13·6	13·2, 14·0	277	265, 290	475	452, 499
Q5 [26·8]	14·1	13·7, 14·5	269	256, 282	477	454, 500
P for trend	0.35		0·80		0·09	
Regression coefficient (95 % CI)	0·005	−0·001, 0·011	−0·25	−0·96, 0·45	1·17	−0·12, 2·46
P	0·09		0·48		0·07	
Confectioneries						
Q1 [5·9]	14·1	13·7, 14·5	270	256, 284	461	436, 485
Q2 [9·0]	13·9	13·5, 14·3	267	255, 280	478	455, 502
Q3 [11·5]	13·8	13·4, 14·2	269	256, 282	480	457, 503
Q4 [14·8]	13·9	13·5, 14·3	280	267, 293	460	436, 483
Q5 [21·6]	13·4	13·0, 13·8	267	254, 281	434	409, 459
P for trend	0·07		0·96		0·036	
Regression coefficient (95 % CI)	−0·007	−0·015, 0·001	0·31	−0·64, 1·26	−1·77	−3·51, −0·03
P	0·07		0·52		0·046	
Rice						
Q1 [4·8]	13·3	12·7, 13·9	265	251, 279	462	436, 488
Q2 [7·2]	14·0	13·6, 14·4	274	261, 286	451	428, 473
Q3 [9·1]	13·8	13·4, 14·2	271	258, 283	463	440, 486
Q4 [10·9]	13·9	13·5, 14·3	266	253, 278	475	452, 499
Q5 [14·4]	14·0	13·4, 14·6	278	264, 292	462	436, 487
P for trend	0·16		0·43		0·64	
Regression coefficient (95 % CI)	0·015	−0·001, 0·030	1·01	−0·83, 2·84	2·54	−0·81, 5·90
P	0·06		0·28		0·14	
Dairy products						
Q1 [3·2]	13·5	13·1, 13·9	249	235, 262	476	452, 500
Q2 [5·6]	13·3	12·9, 13·7	263	250, 276	471	448, 495
Q3 [7·7]	13·5	13·1, 13·9	262	250, 275	459	436, 482
Q4 [10·4]	14·0	13·6, 14·4	278	265, 291	462	439, 485
Q5 [16·1]	14·7	14·3, 15·1	302	289, 316	445	421, 469
P for trend	<0·0001		<0·0001		0·08	
Regression coefficient (95 % CI)	0·020	0·010, 0·030	3·32	2·12, 4·51	−1·78	−3·97, 0·40
P	0·0001		<0·0001		0·11	

Table 3 *Continued*

Monetary costs of self-reported diet (Japanese yen†/1000 kJ)	Biomarker-based estimates of nutrient intake					
	Protein (% of energy)		K (mg/1000 kJ)		Na (mg/1000 kJ)	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
Fruits						
Q1 [1·4]	14·4	14·0, 14·8	272	258, 285	474	450, 497
Q2 [3·0]	14·1	13·7, 14·5	262	249, 275	486	463, 509
Q3 [4·5]	13·7	13·3, 14·1	270	257, 283	464	441, 487
Q4 [6·6]	13·6	13·2, 14·0	280	267, 292	456	433, 478
Q5 [11·6]	13·3	12·9, 13·7	271	258, 283	432	409, 456
P for trend	0·0006		0·57		0·002	
Regression coefficient (95 % CI)	−0·011	−0·021, −0·001	0·64	−0·53, 1·80	−2·56	−4·69, −0·42
P	0·027		0·29		0.019	

**n* 209 in Q1, Q2, Q4 and Q5 and *n* 210 in Q3 for all monetary cost variables. Adjustment was made for survey year (2006 or 2007). For analysis of monetary costs of individual food groups, adjustment was also made for the monetary costs of all other food groups (Japanese yen/1000 kJ, continuous).
†1 Japanese yen = 0·0048 GBP = 0·0062 € = 0·0095 $US in May 2008.
‡Median (all such values).
§A linear trend test was used with the median value in each quintile as a continuous variable in linear regression analysis.
||Expressing changes of biomarker-based estimates of intake of protein (percentage of energy), K (mg/1000 kJ) or Na (mg/1000 kJ) for an increment of monetary costs of 1 Japanese yen/1000 kJ of self-reported diet. Adjustment was made for survey year (2006 or 2007). For analysis of monetary costs of individual food groups, adjustment was also made for the monetary costs of all other food groups (Japanese yen/1000 kJ, continuous).

expensive than less healthful diets, using diet cost and intake variables derived from self-reported dietary intake information[4–9]. Conversely, monetary diet costs seem to be associated with both favourable and unfavourable dietary intake patterns in Japan; monetary cost of self-reported diet was positively associated with self-reported intakes of protein, dietary fibre and key micronutrients, including K, but also positively associated with self-reported intake of Na, fat, SFA and cholesterol and negatively with self-reported carbohydrate intake in young Japanese women[10]. The present findings of positive associations between total monetary costs of self-reported diet and biomarker-based estimates of protein, K and Na intake in young Japanese women are highly consistent with this previous self-report-based Japanese study[10]. Given that the common belief that a healthy diet costs more is supported by the above-mentioned European studies, which rely exclusively on self-reported dietary information, more research using biomarker-based estimates of dietary intake is needed. This need is emphasized by the importance of associations between dietary cost and intake to public health.

In the present study, vegetables and fish were not only the main contributors to total diet cost but also were relatively strongly correlated with it. Additionally, the monetary cost of vegetables was positively associated with protein, K and Na, while that of fish was positively associated with protein, but not with K or Na. Thus, the positive associations of total monetary diet cost with protein, K and Na intake appear to be mainly accounted for by the monetary costs of vegetables and fish. While fruit (in addition to vegetables and fish) is an important contributor to total diet cost in European populations[8,9], its contribution in the present Japanese study was quite small. This important difference, aside from differences in dietary habits, may be one explanation for the differences between Japanese and European studies on the associations between dietary cost and intake.

Several limitations of the present study warrant mention. First, our subjects were selected female dietetic students, not a random sample of Japanese people, and the exact response rate was unknown because of our recruitment procedure (although an approximate response rate was 56 %); these elements of the design may have produced recruitment bias. As such the subjects may have healthier dietary habits than the general population, although with regard to the self-reported intake of energy, protein, K and Na and BMI at least, mean values in the present study (7406 kJ/d, 60·1 g/d, 1985 mg/d, 3626 mg/d and 21·2 kg/m^2, respectively) were relatively comparable to those of a representative sample of Japanese women aged 20–29 years (7000 kJ/d, 62·8 g/d, 1976 mg/d, 3661 mg/d and 20·5 kg/m^2, respectively)[32]. Additionally, students may not be directly paying the costs of food themselves. Thus, our results cannot be extrapolated to males or non-students and of course the general Japanese population, or even to the general student community.

Dietary data were collected using a self-administered semi-quantitative DHQ[20–23]. Although the validity of the DHQ appears reasonable with regard to commonly studied nutritional factors[20–23], the DHQ is not designed specifically to measure monetary diet cost, as with other studies on this topic[4–11]. Additionally, food prices were derived from the National Retail Price Survey[25] and websites of nationally distributed supermarket and fast-food restaurant chains. As this procedure provides 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 (relying on retail food prices as well as self-reported dietary intake information) has been used in all previous observational studies[4–11].

In the present study, a single 24 h urine sample was used, which is not optimal for characterizing individual habitual dietary intake and introduces random errors[33]. Nevertheless, errors in 24 h urine and hence biomarker-based estimates of nutrient intake are thought to be independent of those in self-reported dietary intake (and retail food prices) and hence monetary costs of self-reported diet. This is an important and unique methodological characteristic of the present study, because in all previous studies on this topic (where both monetary diet costs and dietary intake are estimated based on self-reported dietary behaviour obtained by the same dietary assessment method)[4–11], errors in self-reported dietary behaviour are shared by monetary diet cost and dietary intake.

Additionally, concern has been expressed regarding the precision of the correction factors used to estimate dietary intake from 24 h urine. Many variables may influence the percentage of ingested protein (N), K and Na excreted in urine, including the absolute level of dietary intake, the season during which the balance study is conducted, race and cooking method[34]. Here, we used correction factors determined in carefully designed balance studies[12–16], but the use of other correction factors should have little influence on the observed associations between dietary cost and intake. Nevertheless, estimates of biomarker-based nutrient intake themselves should be interpreted with caution, as they are largely dependent on the correction factors used.

Because energy expenditure was estimated by using physical activity level value for light activity, assuming a predominantly sedentary lifestyle in this population at the group level, energy expenditure of some subjects may have been underestimated[18]. However, because no significant difference in physical activity was seen among quintile categories of monetary diet cost (data not shown), it is unlikely that the use of physical activity level value for light activity for all subjects had any major impact on the observed associations between dietary cost and intake, notwithstanding that energy-adjusted biomarker-based estimates of nutrient intake may be on average overestimated.

Finally, several[35–39] although not all[40] intervention studies have reported that nutrient-dense diets consumed as a result of nutrition interventions were not more expensive than lower-quality diets. These intervention studies provided individual instructions 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. The observational nature of the present study did not allow us to investigate directly if the cost of diet changed after nutritional intervention.

In conclusion, the current preliminary study of young Japanese women showed that total monetary costs of self-reported diet were positively associated with biomarker-based estimates of protein, K and Na intake, and appeared largely due to the monetary costs of vegetables and fish. Contrary to the common public health belief that a healthy diet costs more, spending more money for foods may not necessarily ensure healthier diets, at least among young Japanese women. The association of monetary diet costs with dietary intake is an important public health topic, but information based on using objective measures of dietary intake is not available except for the present study. Thus, further research using objective biomarkers of dietary intake, such as serum carotenoid and fatty acid concentrations, would be of interest.

Acknowledgements

This work was supported by grants from the Ministry of Health, Labour, and Welfare, Japan. None of the authors has any conflict of interest to declare. K.M. contributed to the concept and design of the study, the study protocol, data collection and management; coordinated the fieldwork; formulated the hypothesis; analysed and interpreted the data; and wrote the manuscript. S.S. (a principal researcher of this project) contributed to the concept and design of the study, the study protocol, data collection and management, the writing and editing of the manuscript; and formulated the hypothesis. Y.T. and K.U. contributed to the concept and design of the study, the study protocol and data collection. All authors contributed to the preparation of the manuscript and approved the final version submitted for publication. The authors thank Keika Mine, Yoko Hosoi, Mami Itabashi, Tomono Yahata, Asako Ishiwaki and Kyoko Saito (National Institute of Health and Nutrition) for data collection.

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Public Health Nutrition: 12(8), 1092–1098 doi:10.1017/S1368980008004266

Monetary cost of dietary energy is negatively associated with BMI and waist circumference, but not with other metabolic risk factors, in young Japanese women

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Submitted 27 June 2007: Accepted 28 October 2008: First published online 23 December 2008

Abstract

Objective: Little is known about the relationship of dietary cost to health status. The present cross-sectional study examined the association between the monetary cost of dietary energy (Japanese yen/4184 kJ) and several metabolic risk factors.

Design: Monetary cost of dietary energy was estimated based on dietary intake assessed by a self-administered diet history questionnaire and retail food prices. Body height and weight, from which BMI was derived, waist circumference and blood pressure were measured and fasting blood samples were collected for biochemical measurements.

Setting: A total of fifteen universities and colleges in Japan.

Subjects: A total of 1136 female Japanese dietetic students aged 18–22 years.

Results: After adjustment for potential confounding factors, monetary cost of dietary energy was significantly and negatively associated with BMI (P for trend = 0·0024). Monetary cost of dietary energy also showed a significant and negative association with waist circumference independently of potential confounding factors, including BMI (P for trend = 0·0003). No significant associations were observed for other metabolic risk factors examined (P for trend = 0·10–0·88).

Conclusions: The monetary cost of dietary energy was independently and negatively associated with both BMI and waist circumference, but not other metabolic risk factors, in a group of young Japanese women.

Keywords
Monetary cost
Diet
Energy intake
Body mass index
Waist circumference
Japanese women
Epidemiology

While several studies have shown that monetary diet cost is associated with diet quality[1,2], little is known about the relationship of dietary cost to health status. A Spanish study reported an association between higher costs of healthy dietary patterns and lower BMI[3]. The monetary cost of dietary energy was negatively associated with BMI in Japanese women[4]. However, the possible association between dietary cost and other metabolic risk factors has not been investigated. The relationship of monetary cost of dietary energy to health status is an important topic for public health nutrition, because if an independent and direct association actually exists between the cost of dietary energy and health, this may imply that public health interventions aimed at decreasing the energy cost of healthy diets could have a potential to improve population health.

Here, we investigated the association of monetary cost of dietary energy with several metabolic risk factors, including BMI, waist circumference, systolic and diastolic blood pressure, total, HDL and LDL cholesterol, fasting TAG and glucose, and glycated haemoglobin.

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Methods

Subjects

The present cross-sectional study was conducted from February to March 2006 and from January to March 2007 among female dietetic students from fifteen institutions in Japan (n 1176). The study protocol was approved by the Ethics Committee of the National Institute of Health and Nutrition; written informed consent was obtained from each subject and also from a parent for subjects aged <20 years. For analysis, women aged 18–22 years were selected (n 1154). We then excluded women not completing survey questionnaires (n 1), those with extremely low or high reported energy intakes (<2092 or >16 736 kJ/d; n 2), those currently receiving dietary counselling from a doctor or dietitian (n 13) and those with previously diagnosed diabetes, hypertension or CVD (n 1). In each analysis, those with missing values for the outcome variable were also excluded (n 2 to n 34). Final sample size ranged from 1088 to 1136 depending on outcome.

Monetary cost of dietary energy

Dietary habits during the preceding month were assessed using a self-administered, comprehensive, diet history questionnaire (DHQ)[5–7]. Detailed descriptions of the DHQ on its structure, methods used for calculating dietary intake and validity regarding commonly studied nutritional factors have been published elsewhere[5–7]. Briefly, the DHQ is a 16-page structured questionnaire that consists of the following seven sections: (i) general dietary behaviour; (ii) major cooking methods; (iii) consumption frequency and amount of six alcoholic beverages; (iv) consumption frequency and semi-quantitative portion size of 116 selected food and non-alcoholic beverage items; (v) dietary supplements; (vi) consumption frequency and semi-quantitative portion size of nineteen cereals (rice, bread and noodles), soup consumed with noodles and miso (fermented soyabean paste) soup; and (vii) open-ended items for foods consumed regularly (once per week or more) but not appearing in the DHQ[5]. The food and beverage items were selected as foods commonly consumed in Japan, mainly from a food list used in the National Nutrition Survey of Japan, and standard portion sizes were derived mainly from several recipe books for Japanese dishes[5]. Estimates of daily intake for a total of 148 food and beverage items (including five seasonings; g/d) and energy (kJ/d), energy-adjusted intake of protein (percentage of energy), fat (percentage of energy) and dietary fibre (g/4184 kJ) were calculated using an *ad hoc* computer algorithm for the DHQ[5], based on the *Standard Tables of Food Composition in Japan*[8]. Dietary energy density (kJ/g) was calculated based on foods only (excluding all caloric and non-caloric beverages including water)[9]. Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation of dietary intake[5].

Monetary cost of the habitual diet (Japanese yen/d) was calculated by multiplying the amount of each food estimated from the DHQ (g/d) by the estimated price of the food (Japanese yen/g) and summing the products (1 Japanese yen = 0·006 € = 0·008 $US in June 2007), using a total of 135 food items after excluding alcoholic beverages (six items), non-caloric beverages (four items) and water (three items)[10]. The procedure for estimating diet costs was based on the assumption that all foods were purchased and then prepared and consumed at home[11,12]. The price of each food was determined mainly from the National Retail Price Survey 2004 (122 items)[13]. For foods whose price were not published in the survey (thirteen items), prices were taken from the websites of nationally distributed supermarket (Seiyu, Tokyo, Japan) and fast-food restaurant (McDonalds, Tokyo, Japan and Mister Donut, Tokyo, Japan) chains. Costs of combined foods such as pizza were calculated using prices of frozen equivalents[3]. Monetary cost of dietary energy (Japanese yen/4184 kJ) was calculated by dividing the estimated daily cost of the diet (Japanese yen/d) by the daily energy intake (kJ/d) and multiplying by 4184. A detailed description of the cost calculation method as well as monetary cost of each food has been published elsewhere[4].

Metabolic risk factors

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 divided by the square of body height (kg/m^2). 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 pressure were measured on the left arm with an automatic device (model HEM-770A; Omron Health Care, Kyoto, Japan) after the subject had been sitting quietly for ≥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 haemoglobin measurements were also collected in evacuated tubes containing no additives. Blood samples were transported at −20°C by car or aeroplane to ensure delivery to a laboratory in Tokyo, Japan (SRL, Inc. in the 2006 survey and Mitsubishi Kagaku Bio-Clinical Laboratories, Inc. in the 2007 survey). The biochemical variables listed below were assayed at the laboratory within 1–2 d of collection to avoid significant degradation. Serum total, LDL and HDL cholesterol, TAG and glucose concentrations were measured by enzymatic assay methods. Glycated haemoglobin was measured by latex agglutination–turbidimetric immunoassay. In-house quality-control procedures for all assays were conducted at the respective laboratory.

Other variables

In a 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 ≥1 million, city with population <1 million, town or village). The lifestyle questionnaire also assessed living status (living with family, living alone, others), current smoking (yes or no) and whether currently trying to lose weight (yes or no). Rate of eating (slow, medium, fast) was self-reported as part of the DHQ. Physical activity was computed as the average metabolic equivalent-hours per day, on the basis of the frequency and duration of five different activities (sleeping, high- and moderate-intensity activities, walking and sedentary activities) over the preceding month, as reported in the lifestyle questionnaire.

Statistical analysis

All statistical analyses were performed using the SAS statistical software package version 8·2 (SAS Institute Inc., Cary, NC, USA). Linear regression models were constructed (using the PROC GLM procedure) to examine the association between monetary cost of dietary energy and metabolic risk factors. For analysis, subjects were categorized into quintiles according to monetary cost of dietary energy. The mean (and 95 % confidence interval) metabolic risk factor values were calculated by quintiles of monetary cost of dietary energy after multivariate adjustment for potential confounding factors, including residential area, size of residential area, living status, 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, currently trying to lose weight, rate of eating and physical activity; BMI was additionally added as a confounder in all analyses except for that for BMI itself. This was conducted for investigating independent associations between monetary cost of dietary energy and metabolic risk factors. When a significant association was observed in the above model, further adjustment was done for dietary composition (protein, fat and dietary fibre intake) or dietary energy density. This was conducted for investigating possible causal pathways; dietary composition has been shown to be associated not only with metabolic risk factors[14–16] but also with monetary diet cost[4,12,17], while dietary energy density has similarly been shown to be associated not only with metabolic risk factors[9,18] but also with monetary diet cost[2,4,11]. Linear trends with increasing levels of monetary cost of dietary energy were tested by assigning each participant a median value for the category and modelling this value as a continuous variable. We also calculated the regression coefficient (and 95 % confidence interval) of variation of metabolic risk factors by an increase of monetary cost of dietary energy (100 Japanese yen/4184 kJ) by multiple regression analysis with adjustment for the potential confounding factors indicated above (using the PROC REG procedure). All reported *P* values are two-tailed, and a *P* value of <0·05 was considered significant.

Results

Lifestyle, dietary, anthropomorphic and biochemical characteristics of all subjects (*n* 1136; those included in the analyses of BMI, waist circumference, and systolic and diastolic blood pressure) are shown in Table 1. Mean monetary cost of dietary energy was 444 Japanese yen/4184 kJ, while mean BMI was 21·3 kg/m^2 and mean waist circumference was 72·9 cm. These characteristics of all subjects according to quintile of monetary cost of dietary energy are also presented in Table 1. In the higher quintiles of monetary cost of dietary energy, there were more subjects living with the family and fewer subjects living alone. Monetary cost of dietary energy was associated positively with intake of protein, fat and dietary fibre and negatively with dietary energy density. There was also a negative association of monetary cost of dietary energy with BMI and waist circumference. According to the quintile of monetary cost of dietary energy, similar patterns were observed for potential confounding factors among those subjects included in the analyses of cholesterol (total, HDL and LDL) and glycated haemoglobin (*n* 1121), fasting TAG (*n* 1088) and fasting glucose (*n* 1089; data not shown).

Table 2 shows the independent association of monetary cost of dietary energy with metabolic risk factors. Generally, similar results were observed when monetary cost of dietary energy was treated as a categorical variable (quintile) and as a continuous variable. After adjustment for potential confounding factors, monetary cost of dietary energy was negatively associated with BMI (model 1). In further investigation of possible causal pathways, this inverse association disappeared after additional adjustment for dietary composition (model 2), but remained after that for dietary energy density (model 3). Monetary cost of dietary energy also showed a negative association with waist circumference independently of potential confounding factors (model 1), including BMI (model 4). In further investigation of possible causal pathways, this inverse association remained after additional adjustment for dietary composition (model 5) or dietary energy density (model 6). No independent associations were observed between monetary cost of dietary energy and

Table 1 Subject characteristics according to quintile of monetary cost of dietary energy (*n* 1136)*: subset of participants in the Japan Dietetic Students' Study for Nutrition and Biomarkers, 2006 and 2007

	All (*n* 1136)		Quintile of monetary cost of dietary energy: 1 (*n* 227)		2 (*n* 227)		3 (*n* 228)		4 (*n* 227)		5 (*n* 227)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P*†
Monetary cost of dietary energy (Japanese yen/4184 kJ)‡	444	77	343	30	401	11	440	11	479	13	556	50	<0·0001
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	
Residential block													0·15
North (Kanto, Hokkaido and Tohoku)	636	56	125	55	124	55	121	53	138	61	128	56	
Central (Tokai, Hokuriku and Kinki)	275	24	47	21	61	27	56	25	53	23	58	26	
South (Kyushu and Chugoku)	225	20	55	24	42	19	51	22	36	16	41	18	
Size of residential area													0·52
City with population ≥1 million	183	16	30	13	29	13	38	17	42	19	44	19	
City with population <1 million	883	78	189	83	186	82	176	77	168	74	164	72	
Town or village	70	6	8	4	12	5	14	6	17	7	19	8	
Living status													<0·0001
Living with family	683	60	69	30	113	50	147	64	163	72	191	84	
Living alone	405	36	144	36	100	44	77	34	54	24	30	13	
Others	48	4	14	6	14	6	4	2	10	4	6	3	
Survey year													0·002
2006	461	41	83	37	82	36	88	39	94	41	114	50	
2007	675	59	144	63	145	64	140	61	133	59	113	50	
Current smoking													0·29
No	1107	97	217	96	223	98	223	98	223	98	221	97	
Yes	29	3	10	4	4	2	5	2	4	2	6	3	
Currently trying to lose weight													0·65
No	879	77	175	77	176	78	176	77	187	82	165	73	
Yes	257	23	52	23	51	22	52	23	40	18	62	27	
Rate of eating													0·38
Slow	343	30	63	28	71	31	67	29	76	33	66	29	
Medium	344	30	64	28	64	28	80	35	67	30	69	30	
Fast	449	40	100	44	92	41	81	36	84	37	92	41	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Physical activity (total MET-h/d)	33·9	3·1	33·8	3·4	33·7	2·4	34·0	3·4	33·7	2·5	34·4	3·4	0·06
Dietary composition													
Protein (% of energy)	13·5	1·9	11·9	1·5	12·9	1·4	13·4	1·3	14·1	1·4	15·2	1·9	<0·0001
Fat (% of energy)	29·1	5·2	26·2	5·2	28·9	5·0	29·5	4·8	30·1	4·3	31·0	5·1	<0·0001
Dietary fibre (g/4184 kJ)	6·8	2·0	5·6	1·4	6·1	1·4	6·7	1·4	7·2	1·5	8·6	2·5	<0·0001
Dietary energy density (kJ/g)	5·90	0·96	6·49	1·05	6·15	0·92	5·90	0·79	5·65	0·75	5·27	0·88	<0·0001
Metabolic risk factors													
BMI (kg/m²)	21·3	2·7	21·9	2·8	21·2	2·6	21·4	2·6	21·1	2·4	21·1	3·2	0·001
Waist circumference (cm)	72·9	7·1	75·0	7·8	72·5	6·4	73·0	6·8	72·3	6·4	71·7	7·4	<0·0001
Systolic blood pressure (mmHg)	106·4	10·6	106·3	9·7	106·5	11·2	106·5	10·5	106·9	10·4	105·7	11·2	0·84
Diastolic blood pressure (mmHg)	69·3	8·2	69·5	7·5	69·0	7·9	69·3	8·7	69·5	7·7	69·4	9·0	0·95
Total cholesterol (mg/dl)	188·9	31·8	189·3	32·5	186·8	29·5	187·7	31·4	190·0	33·0	190·5	32·7	0·72
HDL cholesterol (mg/dl)	70·6	12·7	70·9	12·4	70·2	12·1	71·2	13·0	69·4	13·4	71·0	12·7	0·56
LDL cholesterol (mg/dl)	107·0	27·2	108·1	27·6	104·8	26·6	105·2	26·7	109·4	27·9	107·2	27·3	0·34
Fasting TAG (mg/dl)	61·1	28·8	61·9	26·5	64·8	34·7	58·6	25·0	61·6	31·7	58·6	24·6	0·13
Fasting glucose (mg/dl)	84·0	6·4	83·8	5·5	84·3	7·2	83·8	6·5	84·9	6·1	83·5	6·5	0·17
Glycated haemoglobin (%)	4·87	0·26	4·85	0·29	4·87	0·26	4·87	0·23	4·86	0·25	4·88	0·27	0·85

MET, metabolic equivalents.

**n* 1121 for cholesterol (total HDL, and LDL) and glycated haemoglobin (224 in the first, second, fourth and fifth and 225 in the third quintiles); *n* 1088 for fasting TAG (217 in the first and fifth and 218 in the second, third and fourth quintiles); and *n* 1089 for fasting glucose (217 in the first and 218 in the second, third, fourth and fifth quintiles).

†For continuous variables, a linear trend test was used with the median value in each quintile as a continuous variable in linear regression analysis; for categorical variables, a Mantel–Haenszel χ^2 test was used.

‡1 Japanese yen = 0·006 € = 0·008 $US in June 2007.