Original Article

Estimation of glycemic and insulinemic responses to short-grain rice (*Japonica*) and a short-grain rice-mixed meal in healthy young subjects

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We estimated glycemic and insulinemic responses to short-grain rice (*Japonica*) and a short-grain rice-mixed meal (i.e. short-grain rice and other ingredients) in three healthy male, and five healthy female subjects aged 22–31 years. A 50 g carbohydrate portion of dry rice was used in this study to estimate the glycemic index (GI) of short-grain rice (Experiment 1). The GI of short-grain rice was 68 (white bread = 100). In Eperiment 2, the subjects took three mixed meals (rice-, bread- and cornflakes-mixed) containing 60 g available carbohydrate, 25–29 g fat, 18–22 g protein, 2331–2486 kJ energy, and 67–123 meal GI in order to detemine whether both the amount and source of carbohydrate consumed determined postprandial glycemic and insulinemic responses of mixed meals. Glycemic response after the rice-mixed meal was significantly lower ($P < 0.05$) than that after the cereal-mixed meal. The predicted glycemic and insulinemic responses, based on GI and the amount of carbohydrate, were related to the observed mean plasma glucose responses. These results suggest that short-grain rice (*Japonica*) grown in Japan should not be classified as a high GI food and that, in a mixed meal, it is a lower glycemic and insulinemic responder compared with bread or cereal mixed meals. Moreover, both the amount and source of carbohydrate consumed determine the glycemic and insulinemic responses after different mixed meals with variable GI.

Key words: glycemic index, short-grain rice, mixed meal, carbohydrate, glucose, insulin, Japan.

Introduction

Postprandial glycemic and insulinemic responses are influenced by the amount of carbohydrate consumed[1] and its glycemic index (GI).[2,3] International tables of GI are now available that compare the GI of many different foods, the implication being that this approach will be helpful in planning meals for individuals, particularly those with diabetes.[2,4] Rice has given a wide range of results in GI studies around the world. The GI of white rice has ranged from as low as 54 to as high as 133 when bread is used as the reference food.[4–6] Because these previous GI studies were almost all performed with long-grain rice (*Indica*), few studies have investigated glycemic response to short-grain rice (*Japonica*), which is eaten every day by most people in Japan.

Rice is the staple food in Japan, providing approximately 30% of total energy and 50% of total carbohydrate intake. The question naturally arises, therefore, whether GI can be used to predict the glycemic and insulinemic responses to rice-mixed meals. Hollenbeck *et al.*[7] and Coulstone *et al.* suggested that the glycemic responses to mixed meals containing different carbohydrate sources did not differ significantly and concluded that the GI approach would have little clinical utility.[8] Wolever *et al.* refuted that conclusion by demonstrating that the observed glycemic response could be predicted by the GI of the component foods.[9–11]

The purpose of this study was to estimate glycemic and insulinemic responses to short-grain (*Japonica*) rice in healthy young subjects. We also tested the hypothesis that both the amount and GI of carbohydrate consumed are important determinations of postprandial glycemic and insulinemic responses to a rice-mixed meal compared with bread- and cornflakes-mixed meals.

Methods

Experiment 1: The glycemic and insulinemic responses to short-grain* (Japonica) *rice

Subjects. Eight healthy volunteers (three male and five female) aged 25 ± 1 years (range: 22–31) with normal glucose tolerance were recruited from the University of Tsukuba (Ibaraki, Japan) to take part in the study. Mean body mass index of subjects was 20.5 ± 0.7 kg/m^2 (range: 17.4–23.2 kg/m^2). All procedures were approved in advance by the Human Use Committee of the University of Tsukuba and were performed in accordance with the Helsinki Declaration of 1975, as revised in 1983. After detailed explanation of this study, each subject gave his or her informed written consent. The subjects were diagnosed as being free of disease by a

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medical examination at Tsukuba Medical Center before the study.

Experiment design. A 50 g carbohydrate portion of short-grain rice (*Koshihikari*) grown in Nigata, Japan was used in this study. Dry rice grains were washed and cooked by boiling for 15 min and steaming for 10 min with a minimum of water (1.5 times the weight of rice). The rice contained 50 g carbohydrate, 1 g fat and 5 g protein per subject. The nutrient contents in the rice were determined using the data book described previously.[12] A 50 g glucose solution was used as the reference food, although the final result was expressed on a scale where white wheat bread was equal to 100. The GI against a bread standard was calculated by multiplying the GI values by 1.42 (100/70, GI of white bread = 70 when glucose is the standard). The two tests were administered in random order. Each test was separated by at least 2 days.

During the period of the study, each subject maintained a normal life style and ate *ad libitum* except for the day before the experiment, on which each subject ate the same dinner (50.4 kJ/kg body weight) at 7:00 pm. The subjects fasted overnight and entered the experiment room at 7:00 am where they rested until the experiments began at 9:00 am. The experiment was performed in the pre-ovulatory phase on the 8th–12th day after the onset of menstruation in the female subjects.[13] After an in-dwelling cannula (kept patent with normal saline) was inserted into a forearm vein and fasting blood samples were collected, the subjects ate rice or drank glucose solution. Further blood samples were collected in order to obtain serum and plasma at 30, 60, 90, 120, 150 and 180 min after the subjects began to eat or drink. All procedures were performed in the experimental room under the same conditions (temperature: 22 ± 1°C; humidity: 60%).

Measurements. Plasma glucose concentrations were determined using the method reported previously.[14] Serum insulin concentrations were determined by enzyme-immunoassay using a kit (Insulin EIA kit) purchased from Seikagaku Kougyou Co. (Tokyo, Japan). The GI and insulin index (II) of short-grain rice was calculated as described previously.[2]

Experiment 2: The glycemic and insulinemic responses to a rice-mixed meal compared with bread- and cereal-mixed meals

Subjects. Subjects participating in this experiment were the same as in experiment 1.

Experiment design. The test meals were rice-, bread-, and cornflakes-mixed meals (various cooked carbohydrate foods, fried egg, leaf vegetables salad and milk). Each meal provided 60 g available carbohydrate, 25–29 g fat, 18–22 g protein, and 2331–2486 kJ. The nutrient contents in the test meals were determined by the data book described previously.[12] Table 1 shows the composition of the test meals. The protocol of meal tolerance testing was the same as in experiment 1 and the test meals were administered in random order. Each test was separated by at least 2 days. The GI of each test meal was calculated, as previously described, as the weighed average of the GI of each food, with the weighting based on the proportion of test meal carbohydrates contributed by the foods.[15]

Results are expressed as means ± SE. The incremental areas under the observed glucose and insulin response curves, ignoring the area beneath the fasting level, were calculated as previously described. Statistical analysis was performed using one-way ANOVA with the test meal as the variable, and the Neuman-Kuels method was used to adjust for multiple comparisons.[11] The predicted effect of the amount of carbohydrate and meal GI on glucose and insulin responses was calculated from equations previously derived from non-diabetic subjects who consumed various amounts of different foods as follows:[10]

$$GR = 1.5 \times GI \times (1 - e^{-10.018D}) + 13$$
$$IR = 2.9 \times (0.6 \times GI + 0.003 \times GI^2) \times (1 - e^{-0.0078D}) + 5$$

In the equations above, GR and IR are defined as the incremental areas under the response curves for glucose and insulin, respectively, expressed as a percentage of those after 50 g carbohydrate from white bread was consumed: GI is meal glycemic index and D is amount of carbohydrate in grams. The GI value for rice resulted from experiment 1 and other GI values as previously described.[4] The correlation coefficient, r, between the predicted relative glucose and insulin responses for the three test meals and the observed means was determined by linear regression analysis. The proportion of the variance of the dependent variable (observed glucose or insulin response), which was accounted for by variation of the independent variable (amount of carbohydrate or predicted response), was determined by r^2.

Table 1. Composition of test meals

	Mixed meals (g)	(g)	(g)	Energy (kJ)	Carbohydrate (g)	Fat (g)	Protein (g)	Meal GI[1] (Bread = 100)	Predicted glucose[2]	Predicted insulin[2]
Variable foods	Rice-mix	Bread-mix	Cornflakes-mix							
Rice (*Japonica)*	66	–	–	991	50	1	5	68	68	56
White wheat bread	–	104	–	1134	50	4	9	100	102	89
Cornflakes	–	–	60	979	50	1	5	119	109	112
Constant food										
Egg	50	50	50	340	0	6	6	–	–	–
Soy bean oil	5	5	5	193	0	5	0	–	–	–
Leaf vegetables	80	80	80	42	1	0	1	–	–	–
Mayonnaise	10	10	10	281	0	7	0	–	–	–
Full-fat milk	200	200	200	496	9	6	6	39	22	11

[1]Glycemic index (GI) value (white bread=100) for rice is from the result of experiment 1 and other GI values are from references.[4]
[2]Predicted responses, relative to those after 50 g carbohydrate from white bread, calculated as follows: glucose response, GR = 1.5 x GI x $(1–e^{–0.018D})$ + 13; insulin response, IR = 2.9 x (0.6 x GI + 0.003 x GI2) x $(1–e^{–0.0078D})$ + 5; GI is the meal glycemic index and D is grams of carbohydrate in the meal.[10]

Results

Experiment 1

The mean glycemic and insulinemic response curves for the short-grain rice are shown in Fig. 1. The calculated GI and insulin index (II) were 48 ± 8 and 65 ± 6 (means ± SE), respectively (glucose = 100).[16] The GI against a white bread as standard (bread = 100) was evaluated as 68.

Experiment 2

The glycemic and insulinemic responses to the three test meals are shown in Fig. 2. The mean incremental area under the glucose and insulin curves for all meals was shown in Table 2. Glycemic response after the rice-mixed meal was significantly lower ($P < 0.05$) than that after the cornflakes-mixed meal (Table 2). On the other hand, differences of insulinemic response among the three meals were negligible (Table 2). The predicted glucose responses, based on GI and amount of carbohydrate, were related to the observed mean plasma glucose response ($r = 0.48$, $P = 0.02$, Fig. 3). Also, the predicted insulin response was significantly related to the observed mean serum insulin response ($r = 0.44$, $P = 0.03$, Fig. 3).

Discussion

The results of this study indicate that the short-grain rice (*Japonica*) usually sold in Japan should not be classified as a high-GI food. The GI value of short-grain rice (GI = 68) was similar to other whole grains, for example, wheat,[17,18] buckwheat,[18] sweet corn,[3,19] and bulgur.[18,20] Millar *et al.* previously investigated the GI values for various rice products using healthy subjects.[16] They suggested that many varieties of rice, whether white, brown, or parboiled, should be classified as high GI foods and that only high-amylose (about 28% amylose) varieties are potentially useful in low GI diets.[16] Most whole grains (i.e. rice and other grains) contain 20% amylose, similar to short-grain rice in Japan. The disagreement between the study of Millar *et al.* and ours concerning the GI for rice products may be due to the difference of types, short- or long-grain, or to differences in cooking methods.

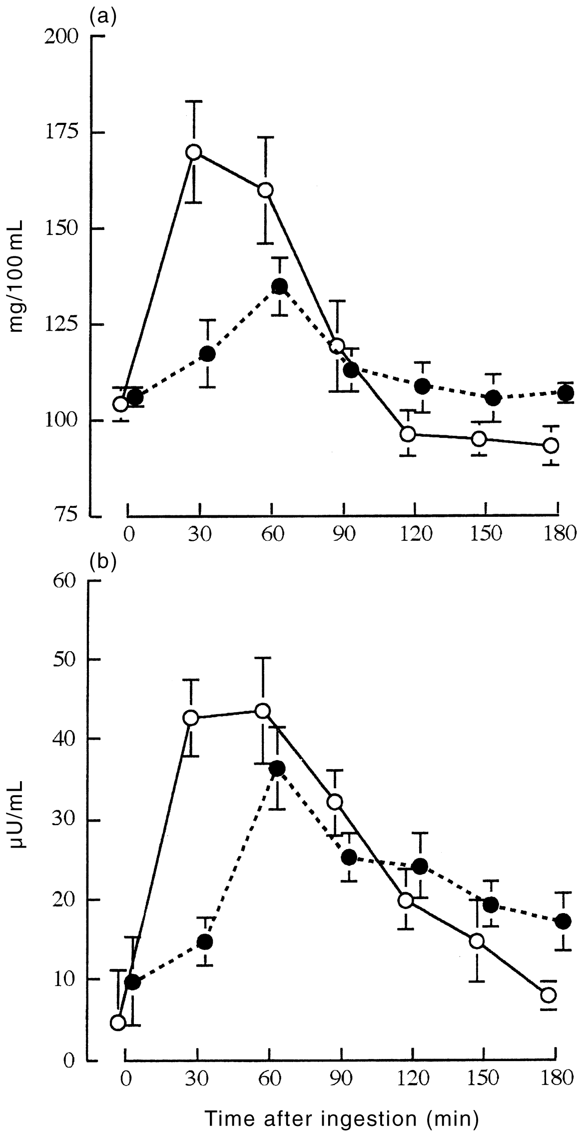

Figure 1. Plasma glucose (a) and serum insulin (b) concentrations after ingestion of a 50 g glucose solution (○) and short-grain (●) rice containing 50 g carbohydrate. Values are means ± SE for eight subjects.

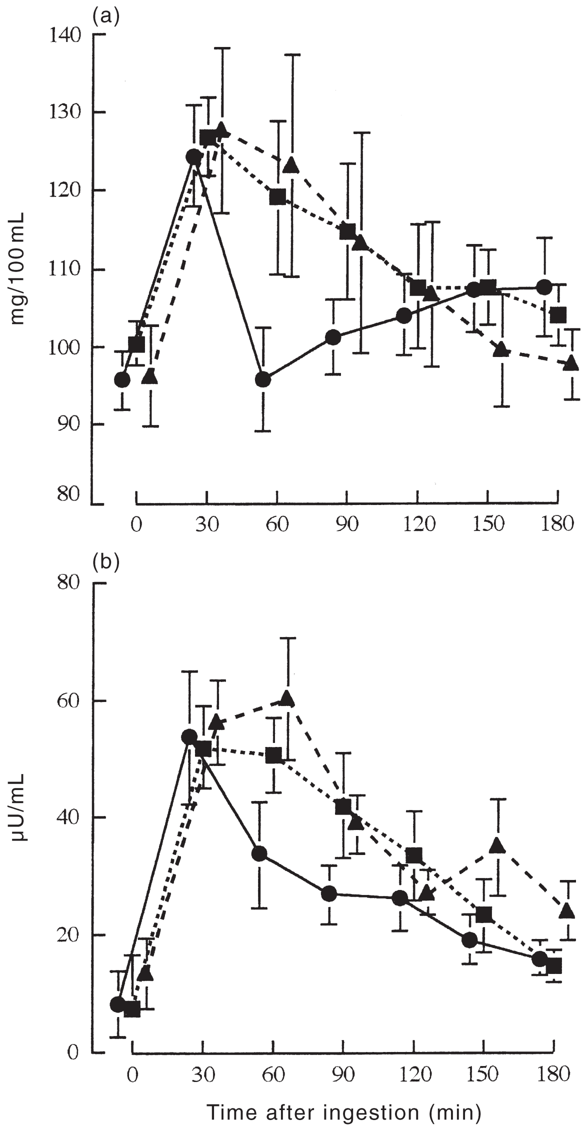

Figure 2. Plasma glucose (a) and serum insulin (b) concentrations after ingestion of rice- (●), bread- (■), and cereal-mixed (▲) meals containing 60 g available carbohydrate, 25–29 g fat, 18–22 g protein, and 2331–2486 kJ energy. Values are means ± SE for eight subjects.

Table 2. Incremental area under the glucose and insulin curves

	Glucose	Insulin
	(mg/100 mL x min x 10^2)	(μU/mL x min x 10^2)
Rice mix	11.3 ± 2.0^a	33.1 ± 6.7
Bread mix	24.5 ± 7.5^{ab}	37.2 ± 4.7
Cornflakes mix	29.5 ± 8.6^b	39.7 ± 5.1

Calculated from Fig. 2. Values are means ± SE for 8 subjects. Within a row, values with different superscripts are significantly different ($P < 0.05$).

This study showed that there are differences in the glycemic responses of healthy subjects to different mixed meals. Moreover, the results supported the hypothesis that both the amount and source of carbohydrate consumed are important determinants of postprandial glycemic and insulinemic responses to mixed meals. Both the amount and source of carbohydrate consumed had to be taken into account to obtain correlations between the composition of the meal and the glucose and insulin responses. This is consistent with the results reported by Wolever and Bolognesi, who tested glycemic and insulinemic responses to five different mixed meals: omelette, spaghetti, cornflakes, oatmeal and barley.[11] In practical terms, the hypothesis that both the amount and source of carbohydrate are clinically important is supported by the results of a recent study. This study showed that dietary advice based on both the amount and source of carbohydrate resulted in better conformance to dietary guidelines and better clinical outcomes in subjects with newly diagnosed diabetes, compared with standard advice based primarily on the amount of carbohydrate.[21]

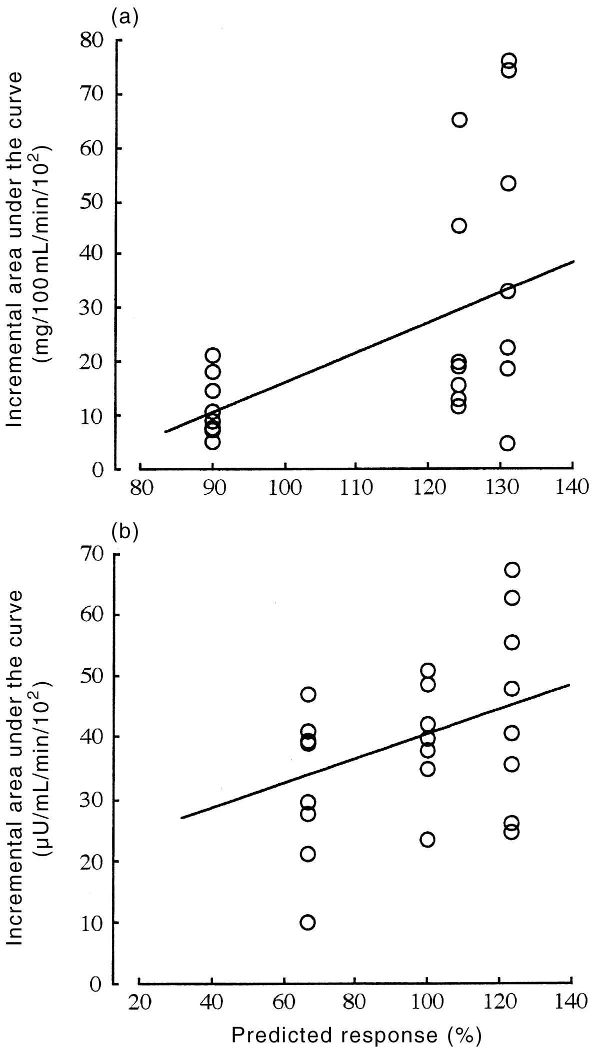

Figure 3. Relationship between predicted and observed response for plasma glucose (a) and serum insulin (b). Prediction was based on amount of carbohydrate and meal GI (see Table 2). Points represent means ± SE for observed incremental areas under the curve for eight subjects. (a) $y = 0.42x – 27.11$; $r = 0.48$; $P = 0.02$. (b) $y = 0.12x + 24.99$; $r = 0.44$; $P = 0.03$.

The predicted glucose and insulin responses of the meals were derived only from the amount of carbohydrate and meal GI, without taking into account the differences in the protein and fat. For single foods, the equations accounted for 92–94% of the variability of glucose responses and 85% of the variability of insulin response.[10] The remainder of the variation was due, at least in part, to experimental error, including within and between subject variation, order effects, and analytic error. In the present study, in the setting of mixed meals, most of the variability of the glucose and insulin responses was explained by the prediction equations, which do not account for the effects of protein and fat. Thus, if protein and fat influenced glucose and insulin responses, the predictions for mixed meals varying in protein and fat content would not be expected to be as accurate as for single foods. This suggests that the carbohydrate component of meals is the primary determinant of postprandial glucose and insulin responses with variation in meal protein and fat appearing to have a negligible effect.

Increasing evidence suggests that diets high in carbohydrate and low in fat are beneficial in improving carbohydrate metabolism in individuals with diabetes.[22] The findings of this study along with other recent reports suggest that the choice of carbohydrate-rich food is important. The reduction of postprandial hyperglycemia and hyperinsulinemia is an important treatment goal and dietary management should be based on the sound knowledge of plasma glucose and serum insulin responses to mixed meals. The incorporation of low GI foods such as legumes into the diet has been shown to reduce both the postprandial and 24-h glucose profile in individuals with diabetes.[11] Legumes are not, unfortunately, a major component of Japanese diets. However, glycemic and insulinemic responses to short grain rice-mixed meals, typical in Japanese diets, were lower than those to bread- or cereal-mixed meals. Although these results need to be confirmed in individuals with diabetes and with many more mixed meals, they suggest that mixed meals with short-grain rice will be a healthy choice for dietary planning.

In conclusion, we suggest that short-grain rice (*Japonica*) grown in Japan should not be classified as a high GI food and that a mixed meal using this rice has a lower glycemic and insulinemic response compared with a bread- or cornflakes-mixed meal. Moreover, we suggest that both the amount and source of carbohydrate consumed determine the glycemic and insulinemic responses after different mixed meals with variable GI.

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