ORIGINAL ARTICLE

Effects of Different Proportion of Carbohydrate in Breakfast on Postprandial Glucose Excursion in Normal Glucose Tolerance and Impaired Glucose Regulation Subjects

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Abstract

Background: The variability of postprandial plasma glucose is an independent risk factor for diabetes. The type and amount of carbohydrate may be important determinants of glycemic control. The aim of the study was to compare the effects of different proportions of carbohydrate in breakfast on postprandial blood glucose fluctuations in impaired glucose regulation (IGR) and normal glucose tolerance (NGT) subjects.

Subjects and Methods: This is a cross-sectional study of two groups including 55 subjects with IGR and 78 individuals with NGT. Their recorded breakfast was sorted into low-carbohydrate (LC) (carbohydrate <45%), medium-carbohydrate (MC) (carbohydrate 45–65%), and high-carbohydrate (HC) (carbohydrate >65%) meals according to the proportion of carbohydrate. Glucose concentrations were continuously measured with a continuous glucose monitoring system, and parameters such as the incremental area under the curve (iAUC) of glucose and postprandial glucose excursion (PPGE) were calculated to evaluate postprandial glucose fluctuations.

Results: The postprandial fluctuations of glucose increased gradually with increased proportions of carbohydrate in breakfast in both IGR and NGT subjects. For the MC and HC meals, iAUC, PPGE, postprandial glucose spike (PGS), and mean blood glucose were significantly greater than those in the NGT group ($P < 0.05$), respectively. The median time to PGS and the time period in which glucose concentrations decreased to baseline after the MC and HC meals in the IGR group were significantly longer than those in the NGT group ($P < 0.01$), respectively. Compared with the NGT subjects for the HC meal, the IGR subjects consuming the MC meal had greater PGS, range of glucose concentrations, SD, and PPGE ($P < 0.05$).

Conclusions: The proportion of carbohydrate in breakfast contributes to glucose excursions in the NGT and IGR subjects. In the IGR subjects, a HC meal should be avoided and a LC meal should be recommended to prevent development of diabetes.

Introduction

A RECENT SURVEY REVEALS that prevalence of impaired fasting glucose and impaired glucose tolerance in China is about 15.5%.¹ Individuals with impaired glucose regulation (IGR) are at markedly higher risk for development of overt type 2 diabetes and cardiovascular disease.^{2,3} Therefore, prevention of type 2 diabetes is becoming a big challenge to public health in China. Indeed, unhealthy lifestyle plays an important role in glucose concentration elevation.^{4,5} The results of the Diabetes Prevention Program (DPP) shows that a

healthy low-calorie, low-fat meal and moderate-intensity physical activity can reduce the incidence of diabetes in high-risk people.⁶ Salmerón et al.⁷ showed that a high glycemic load (GL) meal with a low cereal fiber content increases the risk of diabetes, and thus grains should be recommended to the persons with high risk for diabetes.

Some studies have focused on subjects without diabetes and revealed the different glucose responses to different meals. For example, pea fiber-enriched breads can reduce postprandial plasma glucose (PPG),⁸ and consumption of eggs for breakfast results in less variation of plasma glucose

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in healthy adult men.⁹ Hätönen et al.¹⁰ demonstrated a relatively varied glucose response to a typical Western food (mashed potato) in meals combined with oil, chicken breast, or salad. Gonzalez et al.¹¹ indicated that the glucose level is improved following consumption of porridge made with pinhead oats compared with rolled oats. Nilsson et al.¹² showed certain cereal products with low glycemic indexes (GIs) and high contents of specific indigestible carbohydrates can modulate the glucose response not only in the acute phase, but also during the course of a whole day.

The GL, which is derived by multiplying the amount of carbohydrate consumed in the meal by its GI, has been proposed as a measure of the overall blood glucose-raising potential of the meal.¹³ The amount of carbohydrate is an important determinant of postprandial glucose excursion (PPGE).¹⁴ The PPG level can be controlled by altering the amount of carbohydrate in meals. High-carbohydrate meals increase postprandial blood glucose and insulin concentrations, especially in persons with insulin resistance.¹⁵ Actually, the influence of different proportions of carbohydrate in meals on glucose responses and fluctuations in subjects with prediabetes is poorly understood.

Chinese foods are world-famous for their diversity, and the dietary habits of Chinese people differ greatly from those of people in Western countries, who usually take bread and milk for breakfast. Traditional Chinese foods of breakfast are comparatively complex and vary from different regions. In the Sichuan province of southwest China, local people like to have egg, milk, porridge, noodle, fried rice, dumpling, and so on, in the morning. The majority of breakfast is carbohydrate. However, the effect of Chinese breakfast on PPG profiles has not been fully presented in individuals without diabetes.

Our previous study¹⁶ has proven that intraday glucose variability based on continuous glucose monitoring increases in IGR subjects compared with normal glucose tolerance (NGT) individuals. However, the relationship between meals and postprandial glucose fluctuations in subjects with prediabetes has not been clearly demonstrated. The aim of this study is to compare the effects of breakfast with different proportions of carbohydrate on postprandial blood glucose fluctuations in NGT and IGR subjects.

Subjects and Methods

Study population

Seventy-eight healthy subjects (33 males and 45 females) with NGT 20–70 years of age (mean $\pm$ SD, 41.9 $\pm$ 15.0 years) and 55 IGR individuals (27 males and 28 females) 20–70 years of age (mean $\pm$ SD, 50.9 $\pm$ 12.6 years) were recruited from West China Hospital, Sichuan University, Sichuan, People's Republic of China. They were nonobese with a body mass index between 18.5 and 24.9 kg/m². All subjects were excluded if they had heart, lung, liver, or kidney diseases. The IGR subjects did not take any antihyperglycemic drugs before. All of the participants underwent a 75-g oral glucose tolerance test (OGTT). Confirmation of NGT was based on fasting blood glucose (FBG) of <5.6 mmol/L and 2-h plasma glucose (2hPG) concentration in OGTT of <7.8 mmol/L. IGR was defined as impaired fasting glucose (fasting plasma glucose $\geq$ 6.1 mmol/L and <7.0 mmol/L, 2hPG <7.8 mmol/L) and/or impaired glucose tolerance (fasting plasma glucose $\leq$ 6.1 mmol/L, 2hPG $\geq$ 7.8 mmol/L and <11.1 mmol/L).¹⁷

The NGT subjects did not suffer from hypertension and dyslipidemia. Informed consent, which was approved by the Ethics Committee of West China Hospital, was signed by each participant.

Collection of food data

All subjects received dietary instructions from a nutritionist of our hospital based on 30 kcal/kg/day calorie intake from three daily meals. They recorded the physical form, amount, cooking style, and species of each meal in their daily diet consumption for 3 consecutive days. One hundred thirty-three copies of the recording booklet were collected. Based on fasting state and comparatively regular meals, only breakfast information in three consecutive days was analyzed from the participants in the study. According to proportion of carbohydrate¹⁸ in breakfast, they were divided into three types (Table 1): low-carbohydrate (LC) meal (carbohydrate <45%), medium-carbohydrate (MC) meal (carbohydrate between 45% and 65%), and high-carbohydrate (HC) meal (carbohydrate >65%). In total, there were 77 LC meals, 215 MC meals, and 83 HC meals of breakfast. There were 40 LC, 139 MC, and 42 HC meals in the NGT group and 37 LC, 76 MC and 41 HC meals in the IGR group.

Parameters on evaluation of glucose fluctuations

A continuous glucose monitoring system (CGMS) (CGMS[®] System Gold[™]; Medtronic MiniMed, Northridge, CA), which

TABLE 1. DIFFERENT FOOD CONSUMPTION OF STUDY PARTICIPANTS AT BREAKFAST

Food categories	Food consumptions (containing protein%:fat%:CHO%)
CHO $\leq$ 45%	Milk 27.4%:28.4%:44.2% Fried vegetables 18.8%:47.9%:33.3% Soy milk 51.7%:27.6%:20.7% Egg 53.3%:46.3%:0.4% Meat (pork) 69.6%:30.4%:0% Peanut 28.1%:49.3%:22.6%
45% < CHO $\leq$ 65%	Fried rice with egg 16.3%:26.8%:56.9% Steamed buns with stuffing 15.9%:21.8%:62.3% Yogurt 16.6%:17.7%:63.7% Manchu candied fritter 6.5%:33.3%:60.2% Chocolate cake 6.2%:40.5%:53.3% Cross bridge rice noodle 20.4%:19.4%:60.2%
CHO > 65%	Steamed rice 10.1%:1.3%:88.6% Steamed bun 12%:2.2%:85.8% Oat flakes 16.1%:10.9%:73% Corn 8.5%:1.4%:90.1% Bread 12.8%:8%:79.2% Sweet dumplings 7%:22.1%:70.9% Potatoes 18.4%:0%:81.6% Noodle 14.4%:1.5%:84.1% Porridge 8.7%:1.4%:89.9%

Low-carbohydrate (CHO) diet contains food from the category "CHO $\leq$ 45%," medium-CHO diet contains food from the category "45% < CHO $\leq$ 65%," and high-CHO diet contains food from the category "CHO > 65%."

was approved by the U.S. Food and Drug Administration for clinical application, was used to evaluate the glucose fluctuations of the NGT and IGR subjects. The CGMS was installed in all subjects to monitor glucose levels of interstitial fluid for three consecutive days. The installation of the CGMS has been previously described.¹⁶ Easy GV version 6.0 software (available free for non-commercial use at www.easygv.co.uk) was used to calculate parameters of glucose fluctuations.¹⁹

The incremental area under the curve (iAUC) of glucose concentration, time spent reaching the postprandial glucose spike (PGS), and the time required for glucose concentrations to decrease to baseline were calculated to assess glucose responses to the different types of meals.

PPGE, PGS, minimum values, range of glucose levels, mean blood glucose (MBG), and SD of 36 glucose values within 3 h after breakfast were used to estimate the influence of meals on glucose fluctuation. PPGE was calculated as the peak value of glucose after meals minus the glucose level at the beginning of each meal.

Statistical analysis

All statistical analysis was performed using the Statistical Package for the Social Sciences version 10.0 software (SPSS, Chicago, IL). Comparisons of mean values of normally distributed data within groups were performed by analysis of variance. Comparisons of medians of non-normal distributed data were performed by the Kruskal–Wallis H test. Data were reported as mean $\pm$ SEM values or median with quartile range. $P < 0.05$ was considered significant.

Results

Glucose responses after the LC, MC, and HC meals in the NGT and IGR subjects

The glucose responses to the three different types of meals in the NGT and IGR groups are shown in Figure 1. After the subjects ate breakfast, glucose concentrations increased more rapidly in the IGR group than in the NGT group. The iAUC values for the MC and HC meals in the IGR group were significantly greater than those in the NGT group ($P < 0.001$) (Table 2). After ingestion of MC and HC meals, the PGS ($P < 0.001$) and MBG ($P < 0.001$) of the IGR subjects were significantly higher than those in the NGT subjects, and the time to PGS in the IGR group (57.5 [40–85] min and 60.0 [45–90] min, respectively) was statistically longer than that in the NGT group (40.0 [30–55] min and 40.0 [30–61.25] min, respectively) ($P < 0.001$). The IGR subjects had greater PPGE ($P = 0.001$ and $P < 0.001$, respectively), range of glucose concentrations ($P < 0.001$), and SD ($P < 0.001$) compared with the NGT subjects. The iAUC ($P = 0.342$), SD ($P = 0.673$), range of glucose concentration ($P = 0.581$), PPGE ($P = 0.776$), MBG ($P = 0.055$), PGS ($P = 0.298$), and time spent to PGS ($P = 0.946$) were similar for the LC meals between the IGR and NGT groups (Tables 2 and 3). Although the glucose levels could decrease to the fasting state within 180 min after three meals in the two groups, the median time periods between baseline and back to baseline after the MC and HC meals in the IGR group were significantly longer than those in the NGT group ($P < 0.001$ and $P = 0.008$), which were similar after LC meals between the IGR and NGT groups ($P = 0.442$) (Table 4).

FIG. 1. Glucose response curves after the low-carbohydrate (LC), medium-carbohydrate (MC), and high-carbohydrate (HC) diets in the normal glucose tolerance (NGT) and impaired glucose regulation (IGR) groups.

TABLE 2. INCREMENTAL AREA UNDER THE CURVE OF GLUCOSE FOR DIFFERENT CARBOHYDRATE PROPORTION OF DIETS IN THE NORMAL GLUCOSE TOLERANCE AND IMPAIRED GLUCOSE REGULATION GROUPS

	NGT group	IGR group	P value
LC diet	67.16±66.61	91.10±122.53	0.342
MC diet	108.34±91.24	182.41±153.17	<0.001
HC diet	111.23±87.76	287.70±218.03	<0.001

Data are mean±SD values. The incremental area under the curve of glucose was measured in mmol/L·min.

HC, high-carbohydrate; IGR, impaired glucose regulation; LC, low-carbohydrate; MC, medium-carbohydrate; NGT, normal glucose tolerance.

Compared with the NGT subjects for the HC meal, the IGR subjects for the MC meal had greater PGS ($P<0.001$), range of glucose concentration ($P=0.004$), PPGE ($P=0.042$), MBG ($P<0.001$), and SD ($P=0.007$). PGS ($P=0.628$ and 0.769), range of glucose concentration ($P=0.111$ and 0.173), PPGE ($P=0.066$ and 0.092), MBG ($P=0.228$ and 0.231), and SD ($P=0.162$ and 0.112) in the IGR subjects for the LC meal were similar to those in the NGT subjects for the MC and HC meals.

Subgroup analysis

In the NGT group, PPGE ($P=0.001$ and 0.003) and range of glucose ($P=0.001$ and 0.006) for the LC meal were statistically lower than those for the MC and HC meals. SD of glucose ($P=0.030$) for the LC meal was significantly lower than those for the MC meal.

In the IGR group, PGS ($P<0.001$ and $P<0.001$), range of glucose concentration ($P<0.001$ and $P<0.001$), SD of glucose ($P<0.001$ and $P=0.001$), MBG ($P<0.001$ and $P<0.001$), and PPGE ($P<0.001$ and $P<0.001$) for the HC and MC meals were significantly higher than those for the LC meal. The IGR subjects for the HC meals had greater PGS ($P=0.001$), range of glucose concentration ($P<0.001$), MBG ($P=0.008$), SD of MBG ($P<0.001$), and PPGE ($P<0.001$) than those for the MC meal.

Discussion

This study demonstrates that the IGR group presents greater glucose responses than the NGT group. The postprandial fluctuations of glucose concentration gradually increase with increased carbohydrate proportion of breakfast in both IGR and NGT subjects. The former with the LC meal presents similar postprandial excursions to the latter with the LC, MC, and HC meals.

Glucose responses of foods are classified based on their GI and GL. Although protein and fat can affect postprandial glucose responses, variance of the postprandial glucose and insulin responses are mainly explained by the amount and GI of carbohydrate in meals.²⁰ But, the GI does not take into account the amount of carbohydrate actually consumed, and the estimation of the GI of a mixed meal by calculation is comparatively complex and imprecise.¹⁰ Therefore, postprandial glucose fluctuations are mainly determined by the amount or proportion of carbohydrate in meals. We found that not only in the NGT but also in the IGR groups, glucose variability presented to an increasing degree from the LC to the MC to the HC meals. This indicated that a low proportion of carbohydrate in meals rich in protein and fat produced a blunt glucose response. The result was consistent with other studies.^{13,21} However, one study showed beneficial effects of a high-carbohydrate meal on insulin sensitivity in subjects without diabetes.²²

The glucose responses and postprandial glucose fluctuations for the MC and HC meals in the IGR subjects were significantly higher compared with the NGT subjects, values that were not statistically different for the LC meals between the two groups. The time periods that glucose returned to the fasting value were significantly longer in the IGR subjects consuming the MC and HC meals than those in the NGT group. De Natale et al.²³ demonstrated the long-term effect of a LC, high-monounsaturated fatty acid meal on postprandial plasma glucose in impaired glucose tolerance subjects. Meanwhile, the impaired glucose tolerance subjects were prone to be more sensitive to the varying compositions of

TABLE 3. GLUCOSE FLUCTUATIONS OF DIFFERENT CARBOHYDRATE PROPORTION OF BREAKFAST IN THE NORMAL GLUCOSE TOLERANCE AND IMPAIRED GLUCOSE REGULATION GROUPS

	NGT group (n=78)			IGR group (n=55)		
	LC diet	MC diet	HC diet	LC diet	MC diet	HC diet
PGS (mmol/L)	6.39±1.23	6.92±1.56	6.88±1.26	6.78±1.24	8.12±1.53 ^{ab}	9.21±2.50 ^c
Minimum glucose (mmol/L)	4.86±0.60	4.78±0.71	4.72±0.61	5.06±0.76	5.14±0.93	5.16±1.04
Range of glucose (mmol/L)	1.20 (0.90–1.80)	1.80 (1.30–2.80) ^a	2.10 (1.15–2.80)	1.50 (0.90–2.55)	2.60 (2.00–4.10) ^{ab}	3.70 (2.20–5.75) ^c
SD BG (mmol/L)	0.34 (0.23–0.45)	0.5 (0.32–0.76) ^a	0.55 (0.32–0.86)	0.37 (0.26–0.68)	0.76 (0.52–1.09) ^{ab}	1.14 (0.57–1.56) ^c
MBG (mmol/L)	5.51±0.74	5.73±0.91	5.68±0.75	5.95±0.84	6.63±1.02 ^{ab}	7.15±1.61 ^c
PPGE (mmol/L)	0.90 (0.40–1.50)	1.3 (0.80–2.17) ^{ab}	1.5 (0.70–2.50) ^c	0.9 (0.15–1.80)	2.10 (1.20–3.30) ^{ab}	3.20 (1.40–5.20) ^c
Time to PGS (min)	47.50 (26.25–73.75)	40.00 (30.00–55.00)	40.00 (30.00–61.25)	50.00 (32.50–72.50)	57.50 (40.00–85.00)	60.00 (45.00–90.00)

Data are mean±SD values or median with quartile range.

^aSignificant difference between the low-carbohydrate (LC) and medium-carbohydrate (MC) diets.

^bSignificant difference between the MC and high-carbohydrate (HC) diets.

^cSignificant difference between the LC and HC diets.

IGR, impaired glucose regulation; MBG, mean blood glucose; NGT, normal glucose tolerance; PGS, postprandial glucose spike; PPGE, postprandial glucose excursion; SD BG, SD of mean blood glucose.

TABLE 4. MEDIAN TIME REQUIRED FOR GLUCOSE LEVELS TO DECREASE TO BASELINE AFTER BREAKFAST IN THE NORMAL GLUCOSE TOLERANCE AND IMPAIRED GLUCOSE REGULATION GROUPS

	NGT group	IGR group	P value
LC diet	110 (81–153)	120 (75–175)	0.442
MC diet	100 (65–135)	125 (96–169)	<0.001
HC diet	110 (79–140)	150 (103–180)	0.008

Data are medians with quartile range.

HC, high-carbohydrate; IGR, impaired glucose regulation; LC, low-carbohydrate; MC, medium-carbohydrate; NGT, normal glucose tolerance.

meals. Therefore, LC meals should be recommended to IGR subjects to prevent development of type 2 diabetes.

A large cohort study revealed that a meal high in rapidly absorbed carbohydrates and low in cereal fiber was associated with an increased risk of type 2 diabetes.²⁴ Thus, for IGR individuals who consumed MC or HC meals, acarbose could be used to prevent carbohydrate absorption and improve insulin sensitivity.²⁵

In summary, our data suggest that increasing proportion of carbohydrate in breakfast contributes to the increasing glucose excursions in the NGT and IGR groups. Only the IGR subjects consuming the LC breakfast does not show greater glucose fluctuations compared with the NGT subjects. Therefore, a high proportion of carbohydrate in meals should be avoided, and LC meals be recommended for IGR subjects. A long-term, large-sample, prospective study for standard breakfast may be needed to draw further conclusions on glucose responses to Chinese foods.

Acknowledgments

All of the authors are very thankful to Hongling Yu, Xiangxun Zhang, Hua He, and Xiaojie Yang for their support of this work. This work was supported by the Shanghai United Developing Technology Project of Municipal Hospitals (grant SHDC12006101) and the Science and Technology Bureau of Sichuan Province, China (grant 2011sz0220).

Author Disclosure Statement

No competing financial interests exist for any of the authors.

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