Postprandial metabolic responses to the influence of food form¹–³

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ABSTRACT To determine whether differences in the metabolic response to two common starches could be eliminated by altering the physical form of food, 12 normal and 6 noninsulin-dependent diabetic (NIDDM) subjects were studied after consumption of test loads of whole and blended rice and potato. In normal and NIDDM subjects the lower postprandial glycemia and insulinemia of whole rice was eliminated and became similar to that of whole potato, which was unaffected by blending. The glucagon responses were unchanged and similar in both groups under all study conditions. In both normal and NIDDM subjects the glucose and insulin response to a particular starch is not a stable feature dependent on the unique characteristics of the starch molecule but is affected by food processing and the form in which it is presented to the gastrointestinal tract. Am J Clin Nutr 1988;48:560–4.

KEY WORDS Glycemic index, food form, starch, diabetic diet

Introduction

In recent years a great deal of attention has been focused on the variable metabolic responses seen after the ingestion of different types of simple and complex carbohydrates (1–14). Although numerous studies defined these variable responses, our present knowledge is inadequate to predict consistently and accurately the glycemic response to a particular food, and investigators are beginning to examine the mechanisms underlying the differences in postprandial glucose response to different foods. The importance of food form was demonstrated in a number of studies (15–19). Evaluation of brown and white rice, for example, demonstrated that there was no significant difference in glycemic response between whole white and brown rice but glycemic responses to both were significantly and dramatically higher when the rice was ground into flours (15). Similar results are seen with whole and ground lentils (16). Pureed apples and apple and orange juice elicit higher blood insulin responses than do whole apples or oranges (17, 18) and greater postabsorptive decreases in blood glucose whereas whole grapes elicit a greater insulin response than does grape juice. In addition when white flour is given in the form of spaghetti, blood glucose levels rise less than when the same amount of white flour is given in the form of bread (19). Although researchers have demonstrated that physical disruption can alter the metabolic response to a single food, it has not been demonstrated whether similar disruption of physical form can eliminate the differences seen in the metabolic responses between two different types of foods. Blending cooked rice and potato should eliminate some if not all of the effects of the physical form of these foods. In this study we evaluate whether standardization of the form of two different starches (potato and rice), which have different glycemic effects, can eliminate the differences seen in metabolic response.

Subjects and methods

Subjects

We studied 12 normal volunteers and 6 subjects with noninsulin-dependent diabetes mellitus (NIDDM). Written, voluntary consent forms, approved by the Human Subjects Committee at the University of California, San Diego were signed by all subjects before entry into the study. The clinical characteristics of the study groups are displayed in Table 1. No subject was ingesting any drug known to affect glucose or insulin metabolism during the course of the study. None of the diabetic subjects had been treated with insulin. Those diabetic subjects on oral hypoglycemic agents had discontinued the drug 2 wk before testing. Each person consumed a weight-maintenance diet.

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solid-food diet that contained at least 150–200 g carbohydrate/ 
d throughout the investigation. Procedures followed were in 
 accord with the ethical standards of the Committee on Investiga-
tions Involving Human Subjects, University of California, 
San Diego, and Veterans Administration Medical Center, San 
Diego, CA.

Test loads

Four different meal challenges were given. The composition of 
these test loads are outlined in Table 2. Raw peeled russet 
potatoes (317 g) were cooked at 175 °C in aluminum foil for 1 
h. Sixty-one grams of Uncle Ben’s converted enriched par-
boiled rice (Uncle Ben’s Inc, Houston, TX) was added to 250 
ml of boiling water and simmered for 20 min. Slurries were 
formed by adding cooked rice or potato to 500 mL lukewarm 
tap water in a Waring blender (Model 34BL22, Dynamics Corp 
of America, New Hartford, CT), speed #6 for 2 min. Whole 
products were consumed with 500 mL lukewarm tap water. All 
food forms were consumed warm. The composition of the test 
loads was determined by in vitro chemical analysis by an 
 independent laboratory and the test doses were calculated so that 
the glucose load in all of them was 50 g. All tests were con-
ducted in the morning after an overnight fast and their order 
was randomized for each subject. At 0800 the subject was given 
one of the test loads to ingest. Blood samples for glucose, insu-
lin, and glucagon were timed from the initiation of consump-
tion.

Analytic methods

Samples for serum glucose were measured by the glucose-
oxidase method using a Beckman glucose analyzer (Beckman 
Instruments, Fullerton, CA). Serum immunoreactive insulin 
was measured by the method of Desbuquois and Aurbach (21). 
Samples for glucagon were collected in Trasylol® (Mobay 
Chemical Corp, New York, NY) and assayed with 30 K anti-
sperm (22).

Statistical analysis

Statistical analysis was carried out using analysis of variance 
(ANOVA) for repeated measures and the Student’s t test for 
dependent means. When the assumption of normality was vo-
lated the Wilcoxon signed-rank test was used. All data were 
entered, stored, and analyzed in the UCSD Clinical Research 
Center’s VAX 11/750 computer (Digital Equipment Corp, 
Maynard, MA) using the CINFO data base management and 
analysis software package (Bolt, Beranek, and Newman, Inc, 
Cambridge, MA).

Results

Figure 1 presents the mean serum glucose responses to 
whole rice, whole potato, and the rice and potato slurries in 
normal subjects. When the overall glucose responses of all food 
forms are compared simultaneously, they are not significantly 
different (P[F3,33 = 1.51], NS, ANOVA). On closer inspection of the curves, however, it is apparent that glucose responses after whole-rice ingestion are significantly lower than after potato ingestion.
at 30 min ($p < 0.04$) and 45 min ($p < 0.03$) but plateau at 90–180 min and are higher than whole potato at 180 min ($p < 0.002$). In contrast, when the rice and potato are ingested in the form of slurries, the glycemic responses are comparable throughout. Importantly, when the glucose responses to whole rice are compared with rice slurries, glucose levels are lower with the whole-food preparation than with the slurry except at the latter times. Thus, differences in glycemic patterns between whole rice and whole potato are obliterated when the whole food products are ingested as slurries, and the slurries and whole potato gave equivalent glycemic responses.

The postprandial insulin responses to whole rice, whole potato, and rice and potato slurries are shown in Figure 2. Postprandial insulin responses tend to mimic those of glucose in Figure 1 except they are significantly lower throughout the response after ingestion of whole rice compared with whole potato ($P[F_{1,11} = 15.15], p < 0.003$, ANOVA). However, when rice slurry is consumed, the postprandial insulin levels are much higher than for whole rice ($P[F_{1,11} = 14.59], p < 0.003$, ANOVA) and are now comparable to the postprandial insulin responses seen after whole potato and potato slurry. Thus, ingesting rice as a slurry obliterated the differences in postprandial insulinemia noted after ingesting the whole rice.

Serum glucagon responses after the four test loads are presented in Figure 3 and they are essentially identical for each condition ($P[F_{3,33} = 1.51]$, NS, ANOVA).

Identical studies were performed in a group of NIDDM subjects whose mean fasting glucose level was $215 \pm 13$ mg/dL ($11.9 \pm 0.7$ mmol/L). Although intragroup differences were greater after the various test loads, the results are qualitatively similar to that seen in normal subjects. Thus, the postprandial glucose responses seen in Figure 4 are significantly lower after whole-rice ingestion than after whole potato ($P[F_{1,5} = 10.42], p = 0.02$, ANOVA). When rice is ingested as a slurry, postprandial glycemia is significantly greater (rice vs rice slurry [$P(F_{1,5} = 6.39), p = 0.05$, ANOVA]) and is now comparable to that seen after whole potato or potato slurry. These results demonstrate that differences in glycemic potency of different forms of whole starch-containing food products are related to food form because glycemic differences are no longer present when the food is ingested in the form of a slurry. Although it appears from Figure 5 that the insulin responses are greater after whole potato, these differences are not significant at any time or when the overall responses are compared simultaneously ($P[F_{3,15} = 1.03]$, NS, ANOVA). As in the normal subjects, glucagon responses are comparable after each of the test loads (Fig 6).

Discussion

In recent years it has become apparent that the glycemic potency of starch-containing foods cannot be pre-
dicted by simply knowing the amount of starch ingested. Several laboratories (1–3, 8–12, 14) showed that when patients ingest comparable amounts of different starches, a large range of postprandial glycemic responses is observed. This led to the concept of glycemic indexing (9) in which the glycemic potential of a particular food is specifically tested and rated in reference to a standard food. Although much remains to be done, the glycemic index of a number of foods has now been reported (9, 10, 14). Unfortunately, relatively little is known concerning the factors that govern the glycemic index of a particular starch-containing food. In this report we are studying one of these possible factors, i.e., food form, to determine what influence it has on the postprandial glycemic response to a given starch.

Consistent with our previous studies (1–3) the results show that the glycemic potency of rice is substantially lower than that of potato in both normal and NIDDM subjects. Importantly, our studies also reveal that this difference in glycemic potency is intrinsic to these starch-containing foods as they exist in their native state. When the starch-containing whole food products were blended to form a slurry, no difference in glycemic potency could be detected in either normal or diabetic subjects. The physical process of breaking the starches into smaller particles and ingesting them as an emulsion served to eliminate whatever factors were intrinsic to the whole food that led to the different glycemic potencies. This effect is somewhat different from that seen with legumes. Blending of beans (23) or lentils (24) after cooking does not alter the blood glucose or insulin responses as compared with responses to the whole legume. However, it was demonstrated through in vitro studies that grinding lentils before cooking increased starch hydrolysis rates fivefold (16). Microscopic examination of legumes (white beans) after soaking, soaking and cooking, and soaking, cooking, and blending (25) demonstrated that starch in leguminous seeds is entrapped in parenchyma cells and swells only partially during cooking. This limits α-amylase penetration of the gelatinized starch granules. Blending after cooking released the partially swollen starch granules but in vitro studies of digestion rate showed that digestion, although increased, was not as complete as when disruption of the cell wall preceded cooking (25, 26) allowing a more complete gelatinization of the starch granule and improved susceptibility of α-amylase digestion. In our study, cooking preceded the disruption of the starch granule and yet a dramatically increased glycemic response to the rice starch was seen. In previous studies (15, 27) comparing ground rice to whole rice, the rices were ground before cooking. Our study demonstrates that this is not necessary to achieve the markedly higher postigestion blood glucose and insulin responses.

In our study disruption of the physical form of rice eliminated the difference in metabolic response between whole potato and whole rice. It was demonstrated (28) that there are significant differences in glucose and insulin responses to rices with various amounts of amylase with higher amylase content associated with lower blood glucose and insulin responses and different enzymatic hydrolysis rates. On the other hand, our studies suggest that differences in glycemic potencies of different starch-containing foods are not solely due to variations in the starch molecule per se but rather in the way it is presented to the gastrointestinal digestive and absorptive processes in the whole-food form. The physical access of digestive hydrolytic enzymes to starch molecules differs among foodstuffs and blending a rice product alters this difference so that all starch molecules now have equal availability to digestive enzymes. Blending leads to dispersion and hydration of the starch, which could be an important factor in absorption.

These studies illustrate that the glycemic potency of a particular foodstuff cannot be considered to be a stable characteristic and emphasize the importance of food form. The actual rate and extent of starch digestion is a

FIG 5. Mean serum insulin responses to rice (●), potato (△), rice slurry (□), and potato slurry (▲) in six subjects with NIDDM. (To convert μU/mL to pmol/L, multiply by 7.175.)

FIG 6. Mean serum glucagon responses to rice (●), potato (△), rice slurry (□), and potato slurry (▲) in six subjects with NIDDM. (To convert mg/dL to μmol/L, multiply by 2.869.)
complex issue that depends on a large number of factors not addressed in this study. However, the form in which a food is ingested should be taken into account as dietitians evaluate and prescribe foods and diets for diabetic patients.

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References