Effect of source of dietary carbohydrate on plasma glucose and insulin responses to test meals in normal subjects

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ABSTRACT Plasma glucose and insulin responses were measured in 22 subjects after two meal tolerance tests that varied only in the food source of carbohydrate. Each meal contained 45% carbohydrate, 15% protein, and 40% fat and provided 40% of calculated daily caloric requirement. The meals elicited a similar glucose response; however, the insulin response was significantly lower when rice and corn supplied the carbohydrate as compared to potato and gelatin. The total insulin response, calculated as area under the response curve, was 60% (P < 0.001) greater in the meal with potato and gelatin versus the rice and corn meal. Am. J. Clin. Nutr. 33: 1279–1282, 1980.

Previous studies from our laboratory have indicated that significant differences in plasma glucose and insulin responses resulted when equivalent amounts of glucose were administered as simple versus complex carbohydrates (1). Indeed, variations in these responses were even seen when equivalent amounts of starch (50 g of glucose) were given in the form of either cooked rice, baked potato, whole kernel cooked corn, or white bread (2). Although these observations were of interest, their relevance was certainly open to question. There is no a priori reason to assume that similar results would have been observed if the various carbohydrates had been ingested as part of a mixed meal. The present experiments were undertaken in order to clarify this issue. In these studies we have evaluated the possibility that test meals containing protein, fat, and carbohydrate might produce different plasma glucose and insulin responses as a function of the source of dietary carbohydrate. The results suggest that the metabolic response to equal amounts of carbohydrate administered in a test meal differs with the source of carbohydrate.

Materials and methods

The study population consisted of 22 volunteers, 16 women and 6 men whose mean age was 37 years. No subject was more than 20% above or below desirable body weight as measured by body mass index (3), and none was taking drugs known to affect glucose or insulin metabolism. During the course of the study, subjects were instructed to consume a weight maintenance diet that contained at least 200 g of carbohydrate daily. All subjects had normal oral glucose tolerance tests by the criteria of Fajans and Conn (4).

Each subject underwent two meal tolerance tests within a 1- to 3-week period. The test meals provided

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TABLE 1
Composition of prototype test meals (400 cal)*

<table>
<thead>
<tr>
<th>Food</th>
<th>Amount</th>
<th>Carbohydrate</th>
<th>Protein</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato, baked</td>
<td>195 (raw)</td>
<td>25</td>
<td>3.04</td>
<td>0.20</td>
</tr>
<tr>
<td>Strawberry flavored gelatin</td>
<td>142</td>
<td>20</td>
<td>2.10</td>
<td>0</td>
</tr>
<tr>
<td>Turkey, breast</td>
<td>30</td>
<td>0</td>
<td>9.86</td>
<td>1.20</td>
</tr>
<tr>
<td>Corn oil</td>
<td>8.4</td>
<td>0</td>
<td>0</td>
<td>8.40</td>
</tr>
<tr>
<td>Margarine</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>8.20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>45</td>
<td>15.0</td>
<td>18.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Meal tolerance test 2

<table>
<thead>
<tr>
<th>Food</th>
<th>Amount</th>
<th>Carbohydrate</th>
<th>Protein</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice, boiled</td>
<td>32.3 (dry)</td>
<td>25</td>
<td>2.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Corn, whole kernel</td>
<td>101.0</td>
<td>20</td>
<td>2.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Turkey, breast</td>
<td>30.4</td>
<td>0</td>
<td>10.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Corn oil</td>
<td>7.2</td>
<td>0</td>
<td>0</td>
<td>7.2</td>
</tr>
<tr>
<td>Margarine</td>
<td>10.0</td>
<td>0</td>
<td>0</td>
<td>8.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>45</td>
<td>15.0</td>
<td>18.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

* Absolute amounts varied as a function of each subject's caloric requirement.


In addition, each subject received 50 g of iceberg lettuce and 300 ml of water, decaffeinated coffee, or herb tea.

FIG. 1. Mean (± SEM) plasma glucose (left panel) and insulin (right panel) responses to meal tolerance tests (MTT) 1 and 2.

40% of calculated daily caloric requirement, based upon individual caloric requirements estimated to be 35 cal/kg body weight. The details of the two test meals are seen in Table 1. Each test meal contained 15% protein, 40% fat, and 45% carbohydrate. The protein and fat sources of the two meals were held constant, while the type of dietary carbohydrate varied. The carbohydrate source of meal tolerance test one consisted of potato and strawberry-flavored gelatin (sucrose), while meal tolerance test two contained white rice and whole kernel corn as the source of dietary carbohydrate. The order of the two test meals was randomized.

Subjects were instructed to consume nothing but water from midnight the night before, to eat a moderate size, caffeine-free carbohydrate-containing breakfast before 8:00 AM, and to consume nothing else before re-
ceiving the meal tolerance test at 12:00 Noon. At 12:00 noon subjects were given the test meal, consumed over a 20- to 25-min period. Blood samples were drawn for measurement of plasma glucose and insulin before the meal began, and 30, 60, 120, and 180 min after the beginning of the meal.

Samples were collected in EDTA tubes, and plasma glucose measured by a Beckman Glucose Analyzer (Beckman Instruments, Fullerton, Calif.). Plasma immunoreactive insulin was measured by the method of Desbuquois and Aurbach (5). Statistical analysis was performed by the use of the paired t test.

Results

Mean (± SEM) plasma glucose and insulin responses to the two test meals are seen in Figure 1. Plasma glucose responses shown in the left panel indicate that the two test meals resulted in comparable glycemic responses. On the other hand, the plasma insulin responses to the test meals were quite different (right panel). The potato-strawberry gelatin-containing meal elicited a significantly greater insulin response at 60 (P < 0.02), 120 (P < 0.001), and 180 (P < 0.05) min.

These same data are expressed as the total area under the plasma glucose and insulin response curves in Figure 2. As suggested by Figure 1, the total glucose response to the two meal tolerance tests was almost identical. However, the total insulin response to the meal containing gelatin and potato as the carbohydrate source was 60% greater than that to the meal containing corn and rice (P < 0.001).

Discussion

In this study we have attempted to see if differences in the insulinogenic response to different sources of dietary carbohydrate that we had earlier noted (2) would persist when they were ingested as part of a mixed meal. The answer is clearly in the affirmative. Rice and corn were the least insulinogenic in an earlier study, while potato and dextrose were the most insulinogenic. This information was used to develop the diets used in the current study, and it is clear that adding an equivalent carbohydrate load consisting of potato and gelatin to a test meal resulted in much greater insulin responses than did the addition of rice and corn. Thus, the previously noted difference between glucose and potato on the one hand, and corn and rice on the other, continued to exist when these substances were administered as part of a test meal.

Although the plasma insulin responses to the two test meals were quite different, the plasma glucose responses were comparable. These results are similar to our previous studies in which the various carbohydrates were administered by themselves. The explanation for these observations remains to be defined. We believe the most likely possibility is that the glucose in the gelatin-potato diet is more rapidly absorbed, resulting in higher splanchnic arterial glucose concentrations. The pancreas should respond to this stimulus by secreting insulin at an augmented rate, and plasma glucose levels comparable to those after the rice-corn meal would be maintained because of an increased insulin response. It appears to us that this situation is analogous to that which occurs when oral glucose tolerance tests are performed with varying glucose loads. Under these conditions, increments in amount of glucose administered do not result in different plasma glucose responses, but are associated with concomitant increases in the plasma insulin response (6). We do not know the cause of this presumed increase in rate of absorption of glucose following the gelatin-potato meal, but believe that the most likely explanation is that there is a difference in the physicochemical nature
of the two meals. In this regard, the fiber content of the two meals was estimated to be 8% of carbohydrate for the gelatin-potato meal and 15% for the rice-corn meal (7). Based on previous studies (8, 9), we do not think that this small difference in fiber content could account for the dramatic differences in insulin response. However, the study does not address this question directly, and the explanation for the observed differences in the plasma insulin response to the two test meals remains to be defined.

Finally, it is clear that we are still only dealing with the acute response to the ingestion of different carbohydrates. In order to be of clinical utility these changes must be observed after chronic ingestion of these diets. However, if this could be documented, the implication of these observations is substantial. Very low-density lipoprotein secretion rate and hypertriglyceridemia seem to be closely related to the height of the postprandial insulin response (10–12). Given the frequency of this abnormality of lipoprotein metabolism (13), and the association between hypertriglyceridemia and atherosclerotic heart disease (14,15), the ability to modulate postprandial insulin responses by variations in the source of dietary carbohydrate may lead to more effective dietary management.

References