Calculating meal glycemic index by using measured and published food values compared with directly measured meal glycemic index\(^1\)–\(^3\)

Hayley Dodd, Sheila Williams, Rachel Brown, and Bernard Venn

ABSTRACT

Background: Glycemic index (GI) testing is normally based on individual foods, whereas GIs for meals or di" meals are based on a formula using a weighted sum of the constituents. The accuracy with which the formula can predict a meal or diet GI is questionable.

Objective: Our objective was to compare the GI of meals, obtained by using the formula and by using both measured food GI and published values, with directly measured meal GIs.

Design: The GIs of 7 foods were tested in 30 healthy people. The foods were combined into 3 meals, each of which provided 50 g available carbohydrate, including a staple (potato, rice, or spaghetti), vegetables, sauce, and pan-fried chicken.

Results: The mean (95% CI) meal GIs determined from individual food GI values and by direct measurement were as follows: potato meal [predicted, 63 (56, 70); measured, 53 (46, 62)], rice meal [predicted, 51 (45, 56); measured, 38 (33, 45)], and spaghetti meal [predicted, 54 (49, 60); measured, 38 (33, 44)]. The predicted meal GIs were all higher than the measured GIs (\(P < 0.001\)). The extent of the overestimation depended on the particular food, ie, 12, 15, and 19 GI units (or 22%, 40%, and 50%) for the potato, rice, and spaghetti meals, respectively.

Conclusions: The formula overestimated the GI of the meals by between 22% and 50%. The use of published food values also overestimated the measured meal GIs. Investigators using the formula to calculate a meal or diet GI should be aware of limitations in the method. This trial is registered with the Australian and New Zealand Clinical Trials Registry as ACTRN12611000210976. Am J Clin Nutr 2011;94:992–6.

INTRODUCTION

The glycemic index (GI) is a concept that ranks the glycemic potency of foods (1). It is calculated as the incremental area under the curve (iAUC) for blood glucose after consumption of a test food divided by the iAUC of a reference food containing the same amount of carbohydrate. Although foods are usually tested one at a time rather than as whole meals, there is interest in determining not only the GI of meals but also the GI of whole diets. For this purpose a formula using the GI of individual foods, weighted according to the amount of carbohydrate each food contributes to the meal, has been devised to estimate the GI of whole meals (2). For simple meals of bread and beans, the predicted GI overestimated the measured meal GI in persons with type 1 and type 2 diabetes (3).

Tests were undertaken with more conventional meals containing sources of fat and protein to investigate whether predictable variations in blood glucose concentrations could be found. The blood glucose responses after mixed meals containing rice, spaghetti, or lentils were not different despite the different GI values of the carbohydrate components of the meals (4). A conclusion from this study was that differences in the GI of individual foods were greatly diminished or even “lost” when the foods were incorporated into meals, possibly because fat and protein were found to be more strongly associated with the GI of foods than with the carbohydrate itself (5). In contrast, good agreement was found between the predicted and measured GIs of a meal of bread and beans tested in 6 participants (6).

Part of the inconsistency in results between studies may have been methodologic. Coulston et al (4) used published GI values, whereas Wolever et al (6) tested the GI of the bread and beans, and the meals, all in the same individuals. A problem with the use of published values is that the GI is affected by factors such as variety, ripeness, processing, and cooking; therefore, the foods that Coulston et al used in the meals could have had GIs that were different from the published data. To overcome this problem, pretesting the GI of the individual foods is recommended (7). A study using foods and meals tested for GI in a relatively large sample of individuals has not been carried out.

Our aims, therefore, were to examine the agreement between the measured and predicted meal GIs 1) based on an individual basis by pretesting the foods in each person and testing meals composed of these foods, 2) by averaging the food GI data of the group and using these values to predict the mean GI of meals, and 3) by comparing the meal GIs with the meal GIs derived from published data.

SUBJECTS AND METHODS

Subjects

Exclusion criteria included a diagnosis of chronic disease, use of medications or nutritional supplements known to affect glucose metabolism, food allergies, and pregnancy. Thirty partic-

\(^{1}\) From the Departments of Human Nutrition (HD, RB, and BV) and Preventive and Social Medicine (SW), University of Otago, Dunedin, New Zealand.

\(^{2}\) Supported by a University of Otago research grant.

\(^{3}\) Address correspondence to B Venn, Department of Human Nutrition, PO Box 56, Dunedin, New Zealand. E-mail: bernard.venn@otago.ac.nz.

Received January 13, 2011. Accepted for publication July 5, 2011.

First published online August 10, 2011; doi: 10.3945/ajcn.111.012138.
Participants (15 men and 15 women) with a mean (±SD) age of 34 ± 8.7 y and a BMI (in kg/m²) of 25 ± 4.3 were enrolled.

Methods

The GI of 7 foods were tested: potato mash (Homestyle, Continental; Uniliever Australasia), white rice (Doongara, SunRice CleverRice, Rice Growers Coop), dried spaghetti pasta (Budget, Safeway Traders Ltd), red sweet potato (*Ipomoea batatas*; New Zealand grown), tomato sauce (with extra cheese, Pasta Bake, Dolmio; Mars Food), plain frozen peas (Talleys Group Ltd), and frozen diced carrots (Talleys Group Ltd). Three meals containing these foods plus 50 g pan-fried chicken (Rangitikei corn-fed boneless chicken breast without skin; Tegel Foods Ltd) were also tested.

The foods were purchased in bulk from a local supermarket, and samples (excluding chicken) were sent to a commercial laboratory (Gribbles Veterinary) for the measurement of available carbohydrate content, which was calculated as the difference, including the subtraction of dietary fiber, according to the methods of the Association of Analytic Communities (8). Portions of individual foods containing 25 g available carbohydrate (peas and carrots) or 50 g other foods were tested. The meals contained 50 g available carbohydrate with contributions as follows: main carbohydrate source (potato, rice, or spaghetti), 25 g; sweet potato, 10 g; peas, 4 g; carrots, 3 g; and sauce, 8 g. The proportions of the ingredients were chosen to represent a realistic meal. Food was prepared in the metabolic kitchen, and the GI tests were conducted in the laboratories of the University of Otago, Dunedin, New Zealand.

The tests were conducted over 12 wk, with a start time of between 0700 and 0800. The foods and meals were tested once, and the reference beverages (25 and 50 g glucose) were each tested twice. The testing procedure was conducted in accordance with the recommendations given in a GI methodology article (9). Fasting capillary blood was collected twice before food consumption and postprandially at 15, 30, 45, 60, 90, and 120 min. Foods and meals were consumed at an even pace over 15 min, and the participants remained seated throughout. Blood glucose was measured by using Hemocue instruments (HemoCue AB). Each morning before and after testing, the correct functioning of the instruments was checked by using a manufacturer’s control. The day-to-day CV was 1%. The iAUC for blood glucose was calculated by using the trapezoidal method (2). In addition to the foods being pretested for GI, published values were also obtained from the *International Tables of Glycemic Index and Glycemic Load Values: 2008* (10). Each food had a number of GI values, and the selection of GI was made hierarchically in order of preference from 1) the same brand of food and method of preparation, 2) an Australian/New Zealand tested food, 3) average value, and 4) otherwise closest match. The formula for calculating a meal GI from the individual food GI is shown below.

\[
\text{Meal GI} = \left( \frac{\text{GI}_{\text{foodA}} \times g \text{ available carbohydrate (avail CHO)}_{\text{foodA}}}{g \text{ available CHO}} + \frac{\text{GI}_{\text{foodB}} \times g \text{ available CHO}_{\text{foodB}}}{g \text{ available CHO}} + \ldots \right)/g \text{ available CHO}
\]

Each food or meal was cooked in a batch on the morning of the test, portioned by weighing, and served warm. The Human Ethics Committee of the University of Otago approved the study.

### Table 1
Measured carbohydrate content, serving size, and macronutrient composition of foods contributing 50 g available carbohydrate to meals

<table>
<thead>
<tr>
<th>Food</th>
<th>Carbohydrate (g)</th>
<th>Serving size</th>
<th>Carbohydrate (%g)</th>
<th>Protein (g)</th>
<th>Fat (g)</th>
<th>Fiber (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>12.9</td>
<td>194</td>
<td>25.0</td>
<td>2.9</td>
<td>4.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Rice</td>
<td>38.4</td>
<td>65</td>
<td>25.0</td>
<td>2.0</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Spaghetti</td>
<td>27.1</td>
<td>92</td>
<td>25.0</td>
<td>5.1</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>23.5</td>
<td>43</td>
<td>10.0</td>
<td>0.6</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Peas</td>
<td>12.9</td>
<td>31</td>
<td>4.0</td>
<td>1.8</td>
<td>3.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Carrots</td>
<td>6.0</td>
<td>50</td>
<td>3.0</td>
<td>0.4</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Sauce</td>
<td>8.7</td>
<td>92</td>
<td>8.0</td>
<td>1.8</td>
<td>3.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Chicken</td>
<td>ND</td>
<td>50</td>
<td>0.0</td>
<td>9.9</td>
<td>7.6</td>
<td>0.0</td>
</tr>
</tbody>
</table>

1. ND, not determined.
2. Values reflect the analyzed percentage of carbohydrate in each food.

### Table 2
Geometric mean incremental area under the curves for glucose, foods, and meals and the GI for foods and meals tested in 30 subjects

<table>
<thead>
<tr>
<th>Food</th>
<th>Available carbohydrate (g)</th>
<th>Mean (minimum, maximum) GI (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose²</td>
<td>50</td>
<td>205 (82, 479)</td>
</tr>
<tr>
<td>Glucose²</td>
<td>25</td>
<td>130 (50, 222)</td>
</tr>
<tr>
<td>Carrots</td>
<td>25</td>
<td>40 (11, 133)</td>
</tr>
<tr>
<td>Peas</td>
<td>25</td>
<td>38 (9, 110)</td>
</tr>
<tr>
<td>Sauce</td>
<td>25</td>
<td>45 (10, 130)</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>50</td>
<td>172 (64, 427)</td>
</tr>
<tr>
<td>Potato</td>
<td>50</td>
<td>149 (65, 320)</td>
</tr>
<tr>
<td>Potato meal</td>
<td>50</td>
<td>109 (36, 255)</td>
</tr>
<tr>
<td>Rice</td>
<td>50</td>
<td>99 (45,235)</td>
</tr>
<tr>
<td>Rice meal</td>
<td>50</td>
<td>79 (37, 216)</td>
</tr>
<tr>
<td>Spaghetti</td>
<td>50</td>
<td>115 (55, 293)</td>
</tr>
<tr>
<td>Spaghetti meal</td>
<td>50</td>
<td>78 (32, 214)</td>
</tr>
</tbody>
</table>

1. GI, glycemic index.
2. The mean of duplicate tests.
Statistical analysis

The variance of the iAUCs increased as the means increased; therefore as recommended, the data were log transformed before analysis to stabilize the variance (11). A mixed model, with a random effect for participant, was used to analyze the data because it accounted for the correlation between AUCs for the foods and meals. The GIs (95% CI) of the foods and meals were obtained from the model. The GIs of the meals based on the GI of the foods obtained in this study, both from individuals and as a group, were also estimated. The data were analyzed with Stata Release 11.1 (StataCorp LP).

RESULTS

The measured nutrient compositions of the foods and the amounts of each food contained in meals are shown in Table 1. Each meal contained 50 g available carbohydrate. The energy contents of the meals, followed in brackets by the proportions of energy as carbohydrate, protein, and fat were as follows: potato meal 1730 kJ (48:17:35), rice meal 1570 kJ (53:18:29), and spaghetti meal 1640 kJ (51:20:29). The median (minimum, maximum) fasting glucose concentration of the participants was 4.9 (4.5, 5.4) mmol/L. The reliabilities (intraclass correlation coefficient) based on the repeat glucose beverage tests were 0.51 and 0.75 for the 25- and 50-g glucose loads, with CVs of 23% and 19%, respectively. The mean iAUC and GI for each food, glucose reference beverage, and meal are shown in Table 2. The Bland-Altman plots in Figure 1 show the difference between the estimated and measured GI values for each participant plotted against the average for each food. The mean differences (eg, 8.6 for potato) and the limits of agreement (−40 to 58) are also shown and indicate that the agreement between the estimated and measured GIs was poor.

The correlation (r) between estimated and measured meal GIs were 0.13, −0.01, and 0.30 for the potato, pasta, and rice meals, respectively. In Table 3, the measured meal GI is compared with predicted GI estimates by using individual and group mean data. These values are based on the log-transformed values, so that the differences are presented as ratios. The measured meal GIs are lower than those estimated in all of the comparisons (P < 0.001).

DISCUSSION

The main findings of this study are that the formula used to calculate the GI of mixed meals overestimated the GI of the meals and that the overestimation was unpredictable. The absolute overestimation was 12–19 GI units, and the proportional overestimation was 22–50%, depending on the meal. These overestimates are appreciable, especially considering that each of the carbohydrate-containing foods contributing to the meal had been tested for GI in the same individuals fed the test meals. Some overestimation might be expected given that our meals contained a portion of chicken containing 10 g protein and 7.6 g fat. However, 10 g protein in combination with 5 g fat added to a carbohydrate test food made little difference to the relative glycemic response compared with a control food containing no fat or protein (relative glycemic response: 98%; SEM: 8%) (12). The relative glycemic response tended to be lower when 10 g protein and 10 g fat were tested with a relative glycemic response of 87% (SEM: 5%; P > 0.05). Thus, the chicken in our meal might be expected to lower the GI of the meal by 5–10%. This magnitude of reduction is small compared with the overestimation of the formula, ie, 22–50%. Hence, the fat and protein contents are unlikely to explain the overestimation we found. Justification for the use of the formula to predict the GI of mixed foods came from a study in which the postprandial glycemia of meals containing beef correlated with the estimated meal GI (13). The authors of that study acknowledged that fat and protein may have an effect on glycemia, but the correlation between iAUC and predicted GI was considered evidence in support of the predictive ability of the formula to correctly rank the glycemic potency of meals according to the carbohydrate component. These data differ from those of an earlier study in which the postprandial glycemia for different meals was more similar than could have been predicted on the basis of the published GI values of individual foods (4). These findings suggest that the GI of individual foods is lost when

![Figure 1. Bland-Altman plot showing the difference in GI for each person (n = 30), the mean difference in GI (solid horizontal lines), and the limits of agreement (dashed lines; ±2 SD) for each meal. GI, glycemic index.](image-url)
combined in a mixed meal (5). Several studies have been conducted in which published GI values were substituted into the formula to obtain a predicted meal GI, and this value was compared with the GI of the meal tested in the volunteers. The findings from such studies are inconsistent. For example, agreement to within 10 GI units was found between predicted and measured GI for 4 of 6 meals (14). In comparison, no association between the predicted and measured values was found for a range of typical European breakfasts (15), whereas published GI values were reported to be significant determinants of postprandial glycemia after breakfast meals (16).

When we used the international GI tables (10) to predict the GI of the potato meal, the predicted GI was 73. Hence, on the basis of published values, the potato meal would have been deemed to have a high GI, whereas the measured GI of the meal, 53, was low. Therefore, our data support the contention that there is a loss of discrimination in individual food GI when combined in a meal. Our measured meal GIs were all low (<55), whereas the staple foods would have been classified as high (72 for potato), medium (56 for spaghetti), and low (48 for rice). The carbohydrate staple component of our meals contributed half of the available carbohydrate in the meals. As the proportion of the staple increases in the meal, presumably the meal GI and the staple GI become congruent. We were unable to test this because we held the proportion of the staple constant.

If the overestimation of meal GI by the formula was consistent, then the error may not matter because the distribution of the predicted meal GIs would simply be shifted up the GI scale relative to the measured meal GIs. However, the overestimation in our data was not constant. The formula overestimated the GI of the potato meal by 22% and that of the spaghetti meal by 50%. This disproportionate effect was previously found. The addition of tuna lowered the GI of potato by 18% and that of pasta by 54% (17). Hence, the magnitude of the effect that food combining and the use of the formula have on predicted GI has been found to be variable. How this variability might affect the observational studies in which the formula is used to estimate dietary GI is unknown.

Many observational studies have been undertaken in which associations between dietary GI and risk of chronic disease have been examined with investigators relying on published GI values and the use of the formula (18–20). Study findings are variable. For example, positive associations between GI and risk of type 2 diabetes have been found (21), whereas others have found no association (19). For cardiovascular disease risk, positive, nil, and negative associations have been reported (22–24). In these studies, published GI values were used. A potential problem with the use of published values is that the GI of a food has many determinants. For example, the published GI values for instant mashed potatoes range from 79 to 97 and for boiled carrots from 33 to 49 (10). Therefore, the predicted GI is dependent on which set of values the investigator chooses to substitute into the formula. To what extent the variability between study findings can be attributed to errors in dietary GI estimation is unclear. On the basis of our data, if potato were a staple food in an individual’s diet, the magnitude of difference between the predicted and measured meal GIs would likely lead to misclassification of the dietary GI—the exposure of interest in observational studies.

The use of published GI values and the variability in the overestimation of the formula both indicate that substantial uncertainty may exist in predicted meal and diet GIs. A strength of our study design was that we measured the GI of both individual foods and whole meals in the same subjects in a relatively large sample. However, even with this reliable knowledge of the GI of the individual foods and the composition of the meal, our findings indicate that it is still difficult to estimate a composite GI. Investigators using the formula to calculate meal or diet GIs should be aware of these issues.

The authors’ responsibilities were as follows—BV and RB: designed the study; BV and HD: obtained funding; HD: conducted the study; SW: analyzed the data; and BV: wrote the draft of the manuscript. All authors edited the manuscript. None of the authors had a conflict of interest.

### REFERENCES

8. AOAC International. Official methods of analysis of AOAC Interna-