Low Glycemic Index Breakfasts and Reduced Food Intake in Preadolescent Children

Janet M. Warren, PhD*; C. Jeya K. Henry, PhD*; and Vanessa Simonite, PhD‡

ABSTRACT. Objective. Recent reports have suggested that a low glycemic index (GI) diet may have a role in the management of obesity through its ability to increase the satiety value of food and modulate appetite. To date, no long-term clinical trials have examined the effect of dietary GI on body weight regulation. The majority of evidence comes from single-day studies, most of which have been conducted in adults. The purpose of this study was to investigate the effect of 3 test breakfasts—low-GI, low-GI with 10% added sucrose, and high-GI—on ad libitum lunch intake, appetite, and satiety and to compare these with baseline values when habitual breakfast was consumed.

Methods. A 3-way crossover study using block randomization of breakfast type was conducted in a school that already ran a breakfast club. A total of 37 children aged 9 to 12 years (15 boys and 22 girls) completed the study. The proportion of nonoverweight to overweight/obese children was 70:30. Children were divided into 5 groups, and a rolling program was devised whereby, week by week, each group would randomly receive 1 of 3 test breakfasts for 3 consecutive days, with a minimum of 5 weeks between the test breakfasts. Participants acted as their own control. The 3 test breakfasts were devised to match the energy and nutritional content of an individual’s habitual breakfast as far as possible. All test breakfasts were composed of fruit juice, cereal, and milk with/without bread and margarine; foods with an appropriate GI value were selected. After each test breakfast, children were instructed not to eat or drink anything until lunchtime, except water and a small serving of fruit supplying approximately 10 g of carbohydrate, which was provided. Breakfast palatability, satiation after breakfast, and satiety before lunch were measured using rating scales based on previously used tools. Lunch was a buffet-style meal, and children were allowed free access to a range of foods. Lunch was served in the school hall where the rest of the schoolchildren were eating. Food intake at lunch was unobtrusively observed and recorded. Leftovers and food swapping were recorded, and plate waste was estimated. Lunch intakes were analyzed using a multilevel regression model for repeated measures data. The likelihood ratio statistic was used to determine whether the type of breakfast eaten had a significant effect on lunch intake after allowing for sex and weight status.

Results. The type of breakfast eaten had a statistically significant effect on mean energy intake at lunchtime: lunch intake was lower after low-GI and low-GI with added sucrose breakfasts compared with lunch intake after high-GI and habitual breakfasts (which were high-GI). Overweight and sex did not have a significant effect on lunch intake. Pairwise comparisons among the 3 types of test breakfasts and between each test breakfast and habitual breakfast were made. Lunch intake after the high-GI breakfast was significantly higher than after the low-GI breakfast and low-GI breakfast with added sucrose. The details of the pairwise comparisons were as follows: high-GI versus low-GI = 145 ± 54 kcal; high-GI versus low-GI plus sucrose = 119 ± 53 kcal; low-GI plus sucrose versus low-GI = 27 ± 54 kcal. Lunch intake after the low-GI breakfast and the low-GI breakfast with added sucrose was significantly lower than after the habitual breakfast. The details of the pairwise comparisons were as follows: low-GI versus habitual = −109 ± 75 kcal; low-GI plus sucrose versus habitual = −83 ± 75 kcal; high-GI versus habitual = 36 ± 75 kcal. There were no significant differences between the test breakfasts in immediate satiation. The high-GI breakfasts were rated to be more palatable than the low-GI breakfasts. At lunchtime, hunger ratings were greater after the high-GI breakfast compared with the other 2 test breakfasts on 2 of the 3 experimental days. Prelunch satiety scales were inversely related to subsequent food intake.

Conclusions. These results suggest that low-GI foods eaten at breakfast have a significant impact on food intake at lunch. This is the first study to observe such an effect in a group of normal and overweight children and adds to the growing body of evidence that low-GI foods may have an important role in weight control and obesity management. The potentially confounding effect of differences in the macronutrient and dietary fiber content of the test breakfasts warrants additional study. In addition, the impact of GI on food intake and body weight regulation in the long term needs to be investigated.

Abbreviations. GI, glycemic index; BMI, body mass index; CI, confidence interval.

Currently, there is much interest in the potential of low glycemic index (GI) foods in the management of obesity.1–4 It has been hypothesized that low-GI foods may benefit weight regulation in 2 ways: by promoting satiety and promoting fat oxidation at the expense of carbohydrate oxidation.5 Although no long-term clinical trials
have examined the effects of dietary GI on body weight regulation, single-day studies have shown lower satiety, increased hunger, or higher voluntary food intake after consumption of high-GI compared with low-GI meals.\textsuperscript{1} Two medium-term studies of 5 and 12 weeks also showed improved weight or fat loss on low-GI diets.\textsuperscript{6,7}

A pioneering study by Ludwig et al\textsuperscript{8} showed that obese children who were given high-, medium-, or low-GI breakfasts and lunches of equal-energy content had a voluntary food intake for the rest of the day that was 53% higher after the high-GI breakfast. In an outpatient setting, Speith et al\textsuperscript{9} studied a group of obese children who were prescribed a diet based either on current healthy eating recommendations or on low-GI foods. Reductions in body mass index (BMI) were greater in the low-GI group after accounting for the effects of confounding factors. These findings must be considered preliminary as the children were not randomly assigned to treatment groups. A recent study suggested the prolongation of satiety after low-GI meals in obese adolescents.\textsuperscript{10}

In contrast to the above studies, the present study is novel in 2 ways. First, it investigated the effect of consuming breakfasts of varying GI on appetite and food intake in a group of normal and overweight preadolescent children (aged 9–12 years). Second, the study uniquely measured food intake at lunchtime using unobtrusive observational recordings that enabled an accurate quantification of the nutrient intake.

\textbf{METHODS}

\textbf{Recruitment and Ethical Approval}

Recruitment was undertaken during October 2001 in an Oxford middle school (for children aged 9–13 years), which ran a breakfast club. All years were targeted, with special emphasis on recruiting children in years 5 and 6 (aged 9–11 years). Children were informed about the study in a school assembly, and parents were informed via a school newsletter. Children who had a food allergy, followed a therapeutic diet, or did not habitually eat breakfast were excluded from the study. Thirty-eight children were recruited to the study. Ethical approval for the study was obtained from the University Research and Ethics Committee at Oxford Brookes University (Oxford, United Kingdom).

\textbf{Study Design and Organization}

The study was a 3-way crossover study in which each participant acted as his or her own control. Children were divided into 5 groups, and a rolling program was devised whereby, week by week, each group would randomly receive 1 of the 3 test breakfasts for 3 consecutive days. For each group of children, there was a minimum of 5 weeks between each test breakfast week. Before a group’s first test day, a “trial” lunch was presented whereby children who had consumed their habitual breakfast at home were then provided with lunch at school. The trial day acted as the control breakfast and was also used to refine the technique subsequently used for measuring food intake at lunchtime.

\textbf{Study Details}

The 3 test breakfasts were devised to match energy and nutritional content of an individual’s habitual breakfast. Any outliers, either a very high or low reported energy intake, were amended so that all breakfasts were within a 200- to 500-kcal (837–2092 kJ) range. The 3 test breakfasts are outlined below. Pure fruit juice was served with each breakfast, and its GI reflected the test breakfast. Milk was included in each cereal breakfast, and margarine with or without jelly was included in the bread-based breakfasts. For every breakfast, each child received a constant amount of juice, to avoid fluid volume ingested being a confounding variable to postbreakfast satiation and subsequent measurements. The range (150–250 mL) was based on habitual intake. All breakfasts were prepared at the home of the investigator (J.M.W.) following a recipe for each child and then transported to the school.

1. Low-GI: choice of All-Bran (Kelloggs, Manchester, United Kingdom), non–Swiss-style toasted muesli (Dorset Cereals Ltd, Dunstable, Dorset, United Kingdom), traditional porridge (Quaker Oats, Southall, United Kingdom), or soya and linseed bread (Burgen, Allied Bakers, Maidenhead, United Kingdom). The GI values of these foods were estimated from the international GI tables\textsuperscript{11} and manufacturers’ information, which provided a guide to the GI value of food. The GI of all of the foods was estimated to be <55 (glucose = 100).

2. Low-GI and added sucrose: the choice of food was as described above. Sucrose was added to provide an additional 10% energy; therefore, a breakfast of 200 kcal (837 kJ) had 5 g (20 kcal, 84 kJ) of sucrose added. This breakfast was otherwise identical to the low-GI breakfast. Sucrose has a GI of 68, but as it provided only 10% of energy, this addition did not raise the overall GI of the breakfast above 55.

3. High-GI: choice of Corn Flakes, Coco-Pops, Rice Krispies (all Kelloggs) or white bread (Kingsmill, Allied Bakers, Maidenhead, United Kingdom). The GI values were estimated to be between 75 and 100 (glucose 100).

After each test breakfast, children were instructed not to eat or drink anything until lunchtime, except water and a small serving of fruit (apple, satsuma, or grapes), supplying approximately 10 g of carbohydrate, which was provided for the mid-morning break. The school did not have a shop or vending machine on site, so there was no opportunity for children to buy food during the morning, and no food or drink was permitted in class.

After breakfast, satiation and palatability were measured immediately, and before lunch, satiety was measured. The scales were based on previously used tools\textsuperscript{12–14} and asked, “How full do you feel?” “How much did you like your breakfast?” “How hungry are you?” The rating scale used to assess satiety has been shown by its authors to have greater test-retest reliability than a visual analog scale according to unpublished results.\textsuperscript{15} The scales had not previously been used in children.

Lunch was a buffet-style meal, and children were allowed free access to a range of foods: sandwiches of varied fillings (ham, chicken, egg, peanut butter, yeast extract), salad, savory snacks (cheese sticks, bread sticks, potato chips), cookies, cake, yogurt, flavored curd cheese (low fat), and fresh fruit. Water and fruit flavored beverages were available to drink. Lunch was served in the school hall where the rest of the schoolchildren were eating. Children sat together on a square table, and the investigator (J.M.W.) and an undergraduate nutrition student were seated adjacent to this table. The undergraduate nutrition student was blind to the test meal consumed at breakfast; the investigator (J.M.W.) was not. Unobtrusive observation and recording of food selection was made using a checklist that detailed all of the foods available. Leftovers and food swapping were recorded, and plate waste was estimated. Because many of the foods presented were of known portion size and weight, the amount of food consumed was easily calculated by recording the food eaten and the number of servings consumed. Dietary analysis was undertaken using manufacturers’ nutritional and portion size information, supplemented by a computerized diet package (Diet 5 for Windows 1995; Robert Gordon Institute, Aberdeen, United Kingdom).

\textbf{Baseline Assessments}

\textbf{Anthropometric Measurements}

Anthropometric measures were made at baseline using standard procedures.\textsuperscript{16} Height was measured using a stadiometer (“Seca” Somatometre 200 cm × 0.1 cm). Weight was measured using dial scales (Healthometer Professional Scales, 148 kg × 500 g). BMI was calculated using the standard formula (weight [kg]/height\textsuperscript{2} [m]).

\textbf{Dietary Assessment}

A 24-hour recall of dietary intake was conducted using techniques described by Dornel et al\textsuperscript{17} and food photographs to quantify the data. In addition, a diet history of habitual breakfast

http://www.pediatrics.org/cgi/content/full/112/5/e414
consumption was obtained. The dietary assessments were analyzed using Diet 5 to give a full nutrient analysis.

Participants
A total of 38 children (15 boys and 23 girls) aged 9 to 12 years (mean age: 10.8 ± 0.80 years) were recruited. The children all were UK white in origin. This age group was chosen because of the increasing prevalence of overweight and obesity in young children and the limited work that has been done on the GI concept in prepubertal children. There was 1 withdrawal (female) at the early stage of the study because she was a faddy eater and disliked the breakfasts served. For the 37 children who participated in the study, 362 records of lunch intakes and satiety ratings were made, and there were 8 missing responses.

Statistical Analysis
Lunch intakes were analyzed using a multilevel regression model for repeated measures data18 and were implemented using the software package MLwiN.19 The likelihood ratio statistic20 was used to determine whether the type of breakfast eaten had a significant effect on lunch intake after allowing for sex and weight status. The analysis was undertaken at an individual rather than a group level; all children were from the same classes, and the entire cohort may be assumed to be homogeneous. In addition, the majority of children were sequentially allocated to groups from an alphabetical list to ensure random allocation to group. The use of a multilevel model enabled intake data for children with incomplete records to be included in the analysis,21 increasing the sample of children contributing to the analysis from 30 to 37 and the number of daily records from 300 to 362.

RESULTS

Anthropometry
Children were classified as overweight and obese using the recently published BMI cutoff values for pediatrics, which relate to the adult values of 25 and 30, respectively.22 Almost 30% of the children had BMI values above the normal range for their age and sex (Table 1). Three of the 22 girls were aged 12 years and older, which may help to explain why a greater number of girls is classified as overweight or obese as it is possible that these girls were peripubertal or pubertal. Additional participant demographics are described in Table 2.

Dietary Intake
The mean habitual breakfast and lunch intake obtained from diet histories and a 24-hour recall, respectively, are shown in Table 3.

Composition of Habitual and Test Breakfasts
The test breakfasts were designed to match the energy and macronutrient content of the habitual breakfast as closely as possible. The group mean energy and macronutrient composition of the habitual, low-GI, and high-GI breakfasts and the approximate percentage of energy derived from each macronutrient are shown in Table 4. Note that the second test breakfast was identical to the low-GI

| TABLE 1. Percentage of Children Overweight, Obese, and Nonoverweight |
|-------------------------------------------------|-------|------|-------|
| Obese                                            | 6 (2) | 0 (0) | 9 (2)  |
| Overweight                                      | 24 (9)| 13 (2)| 32 (7) |
| Nonoverweight                                   | 70 (26)| 87 (13)| 59 (13) |

SD indicates standard deviation.

breakfast in all aspects except the addition of sucrose to 10% energy.

Satiety of Breakfasts
The satiation capacity of test breakfasts 1, 2, and 3 were compared separately for the first, second, and third experimental days using the Friedman test. There were no significant differences between the test breakfasts in immediate satiation ($\chi^2 = 1.575$, $df = 2, P = .455$; $\chi^2 = 1.680, df = 2, P = .432$; $\chi^2 = 0.746, df = 2, P = .689$).

Palatability of Breakfasts
The palatability of test breakfasts 1, 2, and 3 were compared separately for the first, second, and third experimental days using the Friedman test, and any significant differences were explored using the Wilcoxon signed ranks test. A significant difference in palatability was found on day 1 and day 2 of the experimental days only (day 1: $\chi^2 = 13.209, df = 2, P = .001$; day 2: $\chi^2 = 13.683, df = 2, P = .000$; day 3: $\chi^2 = 5.512, df = 2, P = .064$). On experimental days 1 and 2, the high-GI breakfast was rated to be significantly more palatable than either the low-GI ($P = .001, P = .008$) or the low-GI with added sucrose ($P = .02, P = .03$) breakfasts. On experimental days 1 and 2, there were no significant differences in palatability between the low-GI breakfast and the low-GI breakfast with added sucrose.

Prelunch Satiety Ratings
The prelunch satiety ratings after test breakfasts 1, 2, and 3 were compared separately for the first, second, and third experimental days using the Friedman test, and any significant differences were explored using the Wilcoxon signed ranks test. A significant difference in satiety was found on day 2 of the experimental days (day 1: $\chi^2 = 3.823, df = 2, P = .148$; day 2: $\chi^2 = 6.500, df = 2, P = .039$; day 3: $\chi^2 = 0.197, df = 2, P = .906$). On day 2, hunger prelunch was significantly greater after the high-GI breakfast than after the low-GI with added sucrose breakfast ($P = .05$).

The relationship of the prelunch satiety rating and subsequent lunch intake was analyzed using Spearman correlation. For each of the 10 lunches, a negative relationship was apparent, ie, a greater hunger rating (a low satiety rating) was associated with higher energy intakes. This relationship was significant on 3 of the 10 lunch occasions: day 3 of the low-GI and low-GI with added sucrose breakfast ($P = .001$ and $P = .008$, respectively) and day 2 of the high-GI breakfast ($P = .001$).
Lunch Intakes After Different Breakfast Types

Details of lunch energy intake at group level are shown in Fig 1. In these analyses, the mean lunch intake after each of the test breakfasts has been used.

On average, girls ate 66 kcal (276 kJ) less than boys at lunchtime, and overweight children ate 93 kcal (389 kJ) more than their lean counterparts. Neither of these differences was statistically significant (sex: \( \chi^2 = 2.855, df = 3, P = .41 \) or being overweight (\( \chi^2 = 4.268, df = 3, P = .23 \)).

Mean lunch intake in the normal-weight children was 18.6 ± 3.9 kcal/kg and 14.9 ± 3.9 kcal/kg in the obese/overweight children. Breakfast type had a statistically significant effect on lunch intake (\( \chi^2 = 68.621, df = 3, P < .001 \)). Seventeen percent of the intraindividual variation within children in lunchtime intake was explained by the type of breakfast eaten. There was no statistically significant evidence that the effect of different breakfasts on lunchtime intake varied according to either sex (\( \chi^2 = 2.855, df = 3, P = .41 \) or being overweight (\( \chi^2 = 4.268, df = 3, P = .23 \)).

Pairwise comparisons among the 3 types of test breakfast and between each test breakfast and habitual breakfast are of particular interest. Confidence intervals (CIs) for pairwise differences between mean calorie intakes are shown in Figs 2 and 3. An overlap (with 0) indicates that results did not differ significantly. Lunch intake after the high-GI breakfast was significantly higher than after the low-GI breakfast and low-GI breakfast with added sucrose; lunch intake after the low-GI breakfast and the low-GI breakfast with added sucrose was significantly lower than after the habitual breakfast. These intervals had a joint 95% CI. Details of the pairwise comparisons are shown in Table 5.

Joint CIs were calculated to allow for multiple comparisons, ensuring an overall CI of 95%. These intervals were wider (ie, more conservative) to allow for multiple tests/intervals. If, however, individual CIs had been used for these several estimates, then this could cause 1 or more to indicate falsely a statistically significant effect, which may be misleading.

Power of Analyses

The CIs reported above show that the sample size had sufficient power to detect differences in lunch intakes within a range of 54 kcal (226 kJ).

Check on Assumptions

Analyses of lunch intake assumed that after allowing for the effects of types of breakfast, sex, and

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**TABLE 3.** Mean Energy Intake of Breakfast and Lunch as Assessed by Diet History and 24-Hour Recall

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 15)</th>
<th></th>
<th>Girls (n = 22)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Breakfast</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>360 ± 126</td>
<td>205–714</td>
<td>348 ± 91</td>
<td>176–522</td>
</tr>
<tr>
<td>Energy (kJ)</td>
<td>1506 ± 527</td>
<td>858–2987</td>
<td>1436 ± 381</td>
<td>739–2184</td>
</tr>
<tr>
<td>Intake/kg (kcal) ± SD</td>
<td>11 ± 5</td>
<td>5–26</td>
<td>9 ± 3</td>
<td>4–18</td>
</tr>
<tr>
<td>Lunch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>605 ± 214</td>
<td>328–983</td>
<td>555 ± 190</td>
<td>293–970</td>
</tr>
<tr>
<td>Energy (kJ)</td>
<td>2531 ± 895</td>
<td>1372–4113</td>
<td>2322 ± 795</td>
<td>1226–4058</td>
</tr>
<tr>
<td>Intake/kg (kcal) ± SD</td>
<td>21 ± 5</td>
<td>11–32</td>
<td>17 ± 6</td>
<td>8–29</td>
</tr>
</tbody>
</table>

**TABLE 4.** Mean Composition of Habitual and Test Breakfasts

<table>
<thead>
<tr>
<th></th>
<th>Habitual</th>
<th>Low-GI</th>
<th>Low-GI and 10% Sucrose</th>
<th>High-GI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal)</td>
<td>361</td>
<td>363</td>
<td>396</td>
<td>359</td>
</tr>
<tr>
<td>Energy (kJ)</td>
<td>1510</td>
<td>1518</td>
<td>1639</td>
<td>1502</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>55.2</td>
<td>53.0</td>
<td>76.7</td>
<td>67.7</td>
</tr>
<tr>
<td>% Energy carbohydrate</td>
<td>60</td>
<td>60</td>
<td>77</td>
<td>73</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>13.0</td>
<td>13.6</td>
<td>13.6</td>
<td>9.1</td>
</tr>
<tr>
<td>% Energy protein</td>
<td>15</td>
<td>15</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>9.8</td>
<td>10.7</td>
<td>10.7</td>
<td>5.8</td>
</tr>
<tr>
<td>% Energy fat</td>
<td>25</td>
<td>25</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Dietary fiber (g)</td>
<td>3.8</td>
<td>5.9</td>
<td>5.9</td>
<td>1.3</td>
</tr>
</tbody>
</table>
weight status, the variations in energy intakes within and between children were normally distributed with constant variance. Diagnostic checks supported these assumptions.

DISCUSSION

There was a significantly lower lunch intake after the low-GI breakfast (with and without the addition of sucrose) compared with lunch intake after the high-GI and habitual breakfasts. In addition, on 2 of the 3 experimental days, hunger ratings were greater (ie, satiety ratings were lower) after the high-GI breakfast compared with the other 2 test breakfasts. Overweight/obesity and sex did not alter the effect of the test breakfasts on lunch intake. Lunch conditions were identical for all groups on every experimental day, suggesting that this was a spontaneous response to the breakfast eaten. Participants had not been informed that the effect of the differing breakfasts was being monitored at lunchtime, and 1 lunch observer was blind to the test breakfast eaten. These measures reduced the potential for participant and observer bias. It is unlikely that observation of the meal affected the children’s behavior as this meal was eaten in a school hall with the rest of the schoolchildren, who were also being closely supervised.

A range of factors that influence the GI of foods has been studied: disruption of plant structure as a result of processing, alteration of amylose:amylopectin ratio, and addition of soluble fiber. These studies all have shown an increase in satiety and/or decrease in food intake as a result of lowering the GI of food. The results of the current study are in keeping with these studies, which reported an increase in satiety and/or a decrease in food intake after the consumption of low-GI food.

In the current study, when a small amount of sugar was added to a low-GI breakfast, a significantly reduced food intake at lunch was still observed. The addition of sucrose may have some practical application, as some low-GI foods may be more acceptable to children with the addition of a small amount of sugar, eg, porridge. Palatability of the low-GI breakfast did not significantly increase with the addition of sucrose, but this may have been underestimated; when toast only rather than breakfast cereal was eaten, the sucrose was added to the breakfast fruit juice as it was considered important to be consistent with the type of added sugar. Palatability has been inversely related to satiety and is likely to affect subsequent food intake.

It is very important in this type of experiment to match macronutrient content to reduce the possibility of confounding variables. Failure to do this has been a criticism of previous studies and makes comparisons of results difficult. Although the differences in the protein, carbohydrate, and fat content of the test breakfasts (Table 4) were smaller than the low- and high-GI of the test meals in the study by Ludwig et al, it must be recognized as a limitation to the study. The macronutrient content of the habitual breakfast (all high-GI breakfasts) was similar to the low-GI breakfast. Therefore, a comparison of the lunch intakes after these breakfasts was important as it helped to eliminate this potentially confounding variable. However, as this meal was studied in a nonrandomized manner before the test meals, confounding by an order effect cannot be ruled out. An additional limitation of the current study was the failure to match dietary fiber content of the test breakfasts.

The results of the current study are particularly important as the effects of one meal on another, with normal inter-meal intervals, are rarely observed in the study of human appetite. This study supports the growing body of evidence that low-GI diets may have a role in weight control and obesity management in young children. The next challenge is to study the long-term impact of GI on overall diet.

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