Breakfasts Higher in Protein Increase Postprandial Energy Expenditure, Increase Fat Oxidation, and Reduce Hunger in Overweight Children from 8 to 12 Years of Age\textsuperscript{1–3}

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Abstract

Background: Currently 1 in every 3 children aged 2–19 y is overweight or obese. Breakfast is a key component of a healthy diet and has the potential to affect children’s health.

Objective: The objective of this study was to determine whether consumption of a protein-based breakfast (PRO) increases postprandial energy metabolism and substrate oxidation, reduces hunger, and reduces food intake at lunch compared with a carbohydrate-based breakfast (CHO) in normal weight (NW) vs. overweight/obese (OW) children.

Methods: A randomized, crossover-design study was conducted in NW (n = 16; 33 ± 1 kg) and OW (n = 13; 46 ± 2 kg) children (10 ± 1 y). Participants were served either a PRO [344 kcal, 21% protein (18 g), 52% carbohydrate, and 27% fat] or CHO [327 kcal, 4% protein (3 g), 67% carbohydrate, and 29% fat]. Energy expenditure (EE), substrate oxidation, appetite, and blood glucose were measured over a 4 h period. Four hour postprandial participants were provided with access to a lunch buffet and food intake was recorded.

Results: After breakfast, OW children in the PRO group had higher (P < 0.0001) EEs and fat oxidation over the 4 h period than did the NW children in the CHO and PRO groups. There was no difference in postprandial EE or carbohydrate oxidation between the CHO and PRO groups over the 4 h period; however, fat oxidation was 16% higher (P < 0.05) after the PRO than the CHO and postprandial carbohydrate oxidation at 4 h was 32% higher after the PRO than the CHO (P < 0.01), independent of weight group. All participants had decreased feelings of hunger (−14%; P < 0.01) and increased fullness (+32%; P < 0.05) after the PRO than the CHO. Finally, there was no difference in food intake within the NW and OW groups.

Conclusion: This study indicates that breakfast macronutrient composition affects postprandial responses in both NW and OW children. A PRO increases postprandial EE and fat oxidation, reduces hunger, and increases satiety when compared with a carbohydrate-based breakfast. \textit{J Nutr} 2015;145:2229–35.

Keywords: protein, breakfast, energy expenditure, children, overweight, appetite, glucose, fat oxidation

Introduction

In the United States, 32% of children are overweight and 17% of children are obese (1), and these numbers are expected to continue to rise (2). Obesity is a major public health concern, increasing the risk of type 2 diabetes, hypertension, and dyslipidemia (3–6). Once restricted to adults, these metabolic diseases are now being diagnosed in children (7–10).

Postprandial energy expenditure (EE)\textsuperscript{6} [thermic effect of feeding (TEF)] is a potential target for management of energy balance, because it can be influenced by the macronutrient composition of the diet (11). In studies of mixed meals, protein has a greater impact on TEF than does carbohydrate (12, 13), increasing TEF by 20% (6). The rise in EE observed with increased protein ingestion is thought to be associated with a lack of storage capacity for dietary protein, which means it must be broken down and used immediately after intake (14). In addition, studies in adults have demonstrated that consumption of animal protein for

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\textsuperscript{3} Supplemental Table 1 is available from the “Online Supporting Material” link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.

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\textsuperscript{5} Abbreviations used: CHO, carbohydrate-based breakfast; EE, energy expenditure; niAUC, net incremental area under the curve; NW, normal weight; OW, overweight/obese; PRO, protein-based breakfast; RQ, respiratory quotient; TEF, thermic effect of feeding.
breakfast results in less variation of plasma glucose and insulin (15, 16), increased satiety, reductions in hunger, increases in TEF, and reduced energy intake throughout the day (16, 17). These are all important when considering the long-term treatment for and/or prevention of obesity in children.

Few studies have tested the effect of breakfast macronutrient composition on postprandial hunger and metabolism in school-aged children. However, some studies have examined the influence of breakfasts with low vs. high glycemic index in children ranging from preschool age through adolescence (18–20). These studies suggest breakfasts with a low glycemic index can reduce hunger (18, 19) and reduce food intake at lunch (19, 20). The decrease in hunger observed with low glycemic index breakfasts in part could be due to the higher protein content of these breakfasts (18, 19). However, the effect of increasing protein at breakfast on hunger, postprandial energy metabolism (TEF), and food intake in school-aged children is unknown. Therefore, the objective of this study was to determine whether consumption of a protein-based breakfast (PRO), increases postprandial energy metabolism and substrate oxidation, reduces hunger, and reduces food intake at lunch compared with a carbohydrate-based breakfast (CHO) in normal weight (NW) vs. overweight/obese (OW) children.

Methods

Participants. NW and OW children (male and female) aged 8–12 y were recruited to participate in the study. Participants were recruited with the use of local school newsletters to parents, the university daily newsletter, social media, word of mouth, and the local radio station. Children who had food allergies, diet restrictions, claustrophobia, or attention disorders, did not habitually eat breakfast (>2 times/wk), were picky eaters (identified by the parent/guardian), were on any other diet-related conditions (e.g., type 1 or type 2 diabetes) that prevented them from eating the breakfasts were excluded from the study. Thirty-five children (15 NW and 20 OW) were selected to participate in the study. Twenty-nine participants completed the study; 3 participants dropped out of the study because of scheduling conflicts, 1 participant was diagnosed with type 2 diabetes after the first testing day, and 1 participant was excluded because he could not finish eating the PRO in the allocated time. Participant characteristics can be found in Table 1. Ethical approval for the study was obtained from the institutional review board at the University of Arkansas. Written consent was obtained from legal guardians of all children who participated in the study and written assent was obtained from the children who participated in the study.

Screening. In order to participate in the study, children were required to undergo 2 screenings. The first screening was a telephone screening with the parent or guardian to determine if the child met the minimum qualifications. For the second screening, participants and their parents or guardians reported to the laboratory, where participants underwent a series of anthropometric and blood glucose measurements. The body weight of barefoot patients was measured to the nearest 0.05 kg with the use of a standard calibrated, balanced scale (Detecto). Height was measured to the nearest 0.1 cm with the use of a standing stadiometer (Detecto) with participants barefoot and in the free-standing position. Participants were classified as either NW, with BMI <85th percentile for age, or OW, with BMI ≥85th percentile on the CDC BMI charts (21). BMI was calculated as weight in kilograms divided by height in meters squared. Body composition (fat-free mass and fat mass) was also assessed with the use of DEXA (Lunar Prodigy, GE Healthcare). Blood glucose concentrations were measured with the finger stick method with the use of a Lifescan One Touch UltraSmart System. Children with glucose concentrations outside of the normal fasting range (<70 mg/dL or >100 mg/dL) were excluded from the study.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>NW</th>
<th>OW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Age, y</td>
<td>9.9 ± 0.3</td>
<td>9.5 ± 0.4</td>
</tr>
<tr>
<td>Height, cm</td>
<td>140.5 ± 1.8</td>
<td>143.0 ± 2.9</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>33.2 ± 1.3</td>
<td>46.2 ± 4.0*</td>
</tr>
<tr>
<td>BMI</td>
<td>16.7 ± 0.4</td>
<td>22.7 ± 1.1</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>49.7 ± 6.3</td>
<td>92.2 ± 1.4**</td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>7.0 ± 0.6</td>
<td>18.6 ± 2.3**</td>
</tr>
<tr>
<td>Fat-free mass, kg</td>
<td>25.6 ± 1.0</td>
<td>28.4 ± 1.9</td>
</tr>
</tbody>
</table>

1 Values are means ± SEMs or n. * Different from NW: *P < 0.05, **P < 0.0001. NW, normal weight; OW, overweight/obese.

Study design. All participants completed 2 visits to the laboratory in a randomized, crossover design with at least 7 d between visits. Parents or guardians were instructed to make sure the participants maintained their usual food intake patterns and activity levels between test day visits; however, food intake and activity were not recorded between visits. The day before their test day visit, parents or guardians were instructed to have their children refrain from eating and drinking caloric beverages after 2000 and report to the test center in a fasted state. Parents or guardians were asked to ensure their child refrained from vigorous physical activity 24 h before the testing day. On the testing day, participants and their parents or guardians reported to the laboratory at 0730. Upon arrival, height and weight, resting EE, fasting blood glucose, and baseline appetite were measured. Participants were then served either a PRO or CHO and were given 15 min to consume the test breakfast. Blood glucose measurements and appetite assessments were taken at 15, 30, 60, 120, and 240 min after the meal. EE was measured at 30, 60, 120, and 240 min after the meal. Participants were permitted to watch television or movies (preapproved to discourage movement) while under the ventilation hood to keep them still and prevent them from falling asleep. Using television or movies to reduce movement of children during testing of EE has been reported previously (22–24). The same entertainment selection was available for each testing day. Between time points, participants were permitted to watch movies and/or television programs, read, or play with electronic devices, as long as they were at rest. At the end of the 240 min testing period, participants consumed an ad libitum buffet-style lunch.

Test breakfasts. After collection of baseline measurements, participants were served either a PRO [344 kcal, 21% protein (18 g), 52% carbohydrate, and 27% fat] or CHO [327 kcal, 4% protein (3 g), 67% carbohydrate, and 29% fat]. The 2 test breakfasts were similar in kilocalories and were controlled for fat and fiber content (Table 2). The PRO consisted of 1 egg (60 g) and 2 egg whites (80 g), 5 g butter, 118 mL orange juice, and 2 slices of white bread (57 g). The CHO consisted of 1 frozen waffle (35 g), 10 g butter, 30 mL maple syrup, and 118 mL orange juice.

EE and substrate oxidation. Resting EE was measured with the use of a TrueMax 2400 metabolic cart (Parvomedics) via indirect calorimetry, with the use of the ventilation hood technique. Resting EE (kilocalories per minute) was measured in 15 s increments during a 30 min rest period (25). To determine TEF, resting EE was measured in 15 s increments during a 20 min rest period. TEF (kilocalories per minute) was determined at 30, 60, 90, 120, and 240 min after the meal (25). Respiratory quotient (RQ), volume of carbon dioxide expelled (VCO₂ liters per minute), and volume of oxygen consumed (VO₂ liters per minute) were calculated from the rate of oxygen consumption and carbon dioxide production. Carbohydrate oxidation and fat oxidation were calculated from the nonprotein RQ (26).
Blood glucose measurement. One blood sample was collected via collection in a capillary tube (Health Management Systems). Blood glucose concentrations were measured with the use of the finger stick method at 0, 15, 30, 60, 120, and 240 min after the meal with the use of a Lifescan One Touch UltraSmart System. Samples were measured in duplicate from the sample collected in the capillary tube and the average was used in analysis.

Appetite and palatability ratings. Participants were asked to rate their perceived hunger, fullness, and desire to eat with the use of a traditional 100 mm visual analog scales (27) with opposing anchors (e.g., “extremely hungry” or “not hungry at all”). The questions included were “how hungry do you feel at this moment,” “how full do you feel at this moment,” “how strong is your desire to eat at this moment,” and “how much food do you think you could eat at this moment.” Participants were also asked to evaluate the appearance (“how much do you like or dislike the appearance of the breakfast foods”) and palatability (“how much do you like or dislike the smell and taste of the breakfast foods”) of the breakfast with the use of a traditional 100 mm visual analog scale with opposing anchors “dislike extremely” or “like extremely.” Appetite assessments were measured at 0, 15, 30, 60, 120, and 240 min after the meal.

Ad libitum lunch buffet. Lunch was served 240 min after the test breakfast. Lunch was consumed as an ad libitum buffet-style meal consisting of a variety of foods from each food group (chicken nuggets, dinner rolls, tossed salad, green beans, mashed potatoes, baby carrots, pineapple, a selection of chips, macaroni and cheese, reduced-fat peanut butter and jelly sandwiches on whole-wheat bread, turkey wraps, low-fat yogurt, pudding, ice cream, a selection of cookies, and apple slices). Subjects were asked to consume the lunch meal until they felt full. All food items taken from the buffet were recorded. Food items were weighed to the nearest gram before and after consumption to determine intake. A nutrient analysis of the foods eaten at lunch was calculated with the use of Genesis R&D nutrient analysis software (ESHA Research).

Statistical analysis. Summary statistics were calculated for all data (sample means and sample standard deviations). Net incremental area under the curve (niAUC) was calculated for EE, substrate oxidation, appetite ratings, and glucose values and used in analyses (28). Two-sample independent t-tests were used to determine initial differences between NW and OW participants and to analyze participant characteristics, breakfast

Table 2: Dietary characteristics of test breakfasts

<table>
<thead>
<tr>
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<th>PRO</th>
<th>CHO</th>
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<tbody>
<tr>
<td>Energy content, kcal</td>
<td>344</td>
<td>327</td>
</tr>
<tr>
<td>Total protein, g</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Total carbohydrate, g</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>Total sugars, g</td>
<td>16</td>
<td>39</td>
</tr>
<tr>
<td>Fiber, g</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Total fat, g</td>
<td>10.5</td>
<td>11</td>
</tr>
<tr>
<td>Breakfast appearance, mm</td>
<td>81 ± 3</td>
<td>78 ± 4</td>
</tr>
<tr>
<td>Breakfast palatability, mm</td>
<td>77 ± 3</td>
<td>68 ± 5</td>
</tr>
</tbody>
</table>

1 Values are means ± SEMs unless otherwise indicated. n = 29. CHO, carbohydrate-based breakfast; PRO, protein-based breakfast.
2 Units are in millimeters according to a traditional 100 mm visual analog scale.

Figure 1: Postprandial EE and substrate oxidation after ingestion of either a CHO or PRO in NW and OW children. Data are means ± SEMs; NW n = 16, OW n = 13. EE over time per weight group and niAUC for EE for each breakfast type, with weight groups combined (A). FO over time per weight group and niAUC for FO for each breakfast type, with weight groups combined (B). CO over time per weight group and niAUC for CO for each breakfast type, with weight groups combined (C). *Different from NW, P < 0.05; ns, P ≥ 0.05. CHO, carbohydrate-based breakfast; CO, carbohydrate oxidation; EE, energy expenditure; FO, fat oxidation; niAUC, net incremental area under the curve; NW, normal weight; OW, overweight/obese; PRO, protein-based breakfast.

Protein increases postmeal metabolism in children
palatability, and comparisons of niAUC between test breakfasts (PRO vs. CHO). Energy and macronutrient intake at lunch were analyzed with the use of 1-factor ANOVA. Two-factor, crossover, repeated measures ANOVA was used to examine significant differences between breakfast and weight groups over time for EE, TEF, RQ, VO₂, VCO₂, blood glucose, and appetite ratings. The Bonferroni correction for multiple comparisons was applied when significance was observed within the analyses. Results are reported as means ± SEMs. All analyses were conducted with the use of Prism GraphPad Software, version 6.0. *P < 0.05 was considered statistically significant.

**Results**

**Participant characteristics.** The physical characteristics of the participants are presented in Table 1. There was no significant difference in age, height, and fat-free mass between NW and OW participants. Body weight, BMI percentile, and fat mass were significantly higher (P < 0.05) in OW participants.

**EE and substrate oxidation.** EE and substrate oxidation are presented in the line graphs (individual time points) and bar graphs (niAUC) in Figure 1. The OW children consuming the PRO (4.09 ± 0.36 kcal/240 min) had significantly higher (P < 0.05) postprandial EEs than did the NW children consuming the CHO (3.68 ± 0.12 kcal/240 min) and the NW children consuming the PRO (3.64 ± 0.16 kcal/240 min) at each time point (Figure 1A).

Fat oxidation was 16% higher (P < 0.05) after consumption of PRO than CHO, independent of weight group (Figure 1B). The niAUC was not different between the CHO and PRO for carbohydrate oxidation (Figure 1C). Postprandial carbohydrate oxidation at 4 h was 32% higher after the PRO than the CHO (P < 0.01), independent of weight group.

**Appetite and palatability.** Results for perceived hunger, fullness, desire to eat, and prospective food consumption are presented in the line graphs (individual time points) and bar graphs (niAUC) in Figure 2. For each appetite response, there was a main effect of time, body weight, diet, and diet over time (P < 0.05 for each). However, there was no effect of body weight over
time. Consumption of the PRO resulted in greater appetite control and satiety than did the CHO, based on the niAUC values ($P < 0.05$). Participants had decreased hunger ($-14\%$; Figure 2A), increased fullness ($+32\%$; Figure 2B), decreased desire to eat ($-30\%$; Figure 2C), and decreased prospective food consumption ($-10\%$; Figure 2D) after the PRO than the CHO, independent of body weight. Additionally, participants were asked to evaluate how much they liked the taste and appearance of the test meals upon completion of eating the breakfast. There was no difference in how the participants rated the appearance and palatability of the PRO and CHO (Table 2).

**Blood glucose.** There was no effect of breakfast type or body weight over time for blood glucose (Figure 3). There was also no difference in niAUC glucose response between diets. Both test breakfasts resulted in an increase in glucose values by 30 min; however, the NW children consuming the CHO had significantly higher ($+10\%; P < 0.05$) glucose values at 30 min than did the NW children consuming the PRO. In addition, consumption of the PRO resulted in higher glucose values at 240 min after the meal than did consumption of the CHO ($93.7 \pm 1.1$ vs. $88.1 \pm 1.3; P < 0.01$), independent of body weight.

**Ad libitum lunch intake.** Energy intake at lunch is provided in Table 3. There was no significant effect of breakfast type on energy intake at lunch within either the NW or OW groups. However, the OW group had significantly higher energy intake at lunch ($1036 \pm 97$ kcal vs. $707 \pm 97$ kcal), independent of the breakfast type consumed, than did the NW group ($P < 0.05$). Additionally, all participants selected similar macronutrient contents as percentage of energy intake at the lunch meal.

**Discussion**

To our knowledge, this is the first study to examine the role of protein intake at breakfast on postprandial EE, substrate oxidation, glucose metabolism, and appetite in healthy 8- to 12-y-old NW and OW children. Our results show that consumption of a PRO (22% energy from protein; 18 g protein) compared with a CHO (4% energy from protein; 3 g protein) led to postprandial reductions in perceived hunger and prospective food consumption and increases in perceived fullness and decrease in desire to eat, independently of body weight, after the test meals. OW participants had higher EEs than did NW subjects. These differences existed at rest, as well as at each time point. Fat oxidation was dependent on breakfast type. After the PRO, fat oxidation was higher in the OW participants than in their NW counterparts. There was no difference in energy intake at lunch with either breakfast within each weight group. Taken together, these data suggest that incorporating a breakfast higher in protein into the diet of school-aged children may be important in increasing satiety and increasing EE, which could contribute to improving energy balance and reducing obesity in OW children.

Diets higher in protein and lower in carbohydrate have been shown to improve body composition (29, 30), improve glycemic control (15, 31, 32), increase satiety (16, 33), and increase postprandial energy metabolism (33) in adults. However, the effect of higher protein diets on children is less understood. Results from one randomized study suggest that diets higher in protein with a low glycemic index can be protective against obesity in children aged 5–18 y (34) and diets higher in protein can lead to smaller waist circumference, blood pressure, insulin, and serum cholesterol than lower-protein diets in children from the same age group.

There have been a limited number of studies testing the effects of breakfast macronutrient composition on satiety and subsequent food intake in 8- to 12-y-old children, with most studies focusing on the role of glycemic index at breakfast (19, 35–38). A majority of the studies that have been conducted were in a preschool population and examined the difference of glycemic index on satiety and food intake and not macronutrient distribution of the breakfast (18, 19). These studies have shown that children consuming breakfasts with a lower glycemic index remain full longer, with no effect on food intake at lunch (18). Although not examined directly, the decrease in hunger observed likely is due to the higher protein and fat content of the low glycemic index breakfasts compared with high glycemic index/breakfast.
high carbohydrate breakfasts (18). The results from this study demonstrate that a PRO is more satiating than a CHO and has the same effect in both NW and OW children. However, the increase in feelings of satiety from the PRO did not result in reduced food intake at lunch. This could be because the satiety values had returned to fasted levels by 240 min and participants reported higher hunger levels (21%) than their fasted values. OW participants consumed substantially more calories (~300 kcal) at lunch than NW children, which was expected because of their greater body weight and size compared with NW children. Interestingly, all participants self-selected and consumed a lunch with a similar macronutrient content (15% carbohydrate, 45% protein, and 40% fat), independently of caloric intake.

Children who regularly consume breakfast have better nutritional profiles and improved cognitive function, and are less likely to be overweight than their breakfast-skipping peers (39). However, data suggest that it is not only the frequency of breakfast, but the quality of breakfast (e.g., macronutrient composition) that is essential for appetite and blood glucose control, potentially reducing the risk of developing obesity and type 2 diabetes (40).

In this study, there was no effect of body weight classification on glycemic response. However, when observing the effect of a PRO vs. CHO, participants had a blunted glucose response at 30 min after the PRO. In addition, at the end of the 240 min postprandial time point, blood glucose concentrations were significantly higher (6.3%) after the PRO than the CHO. These data suggest that consumption of a PRO has the potential to reduce postprandial hypoglycemia in both NW and OW children.

One limitation is the duration of the study. This study explored the postprandial effect of a PRO vs. CHO with the use of a single meal. Future studies should explore the effects after a longer adaption to the test breakfasts. A second limitation is the diet composition. In designing the breakfasts, we aimed to keep fiber content low so that all effects of the breakfast meal could be attributed to either a carbohydrate or protein effect. However, several studies show that breakfasts with a low glycemic index (e.g., high fiber content) can enhance satiety and improve glycemic control compared with breakfasts with a high glycemic index (18–20). Another measurement at 180 min also would have been beneficial to determine when the postprandial responses for glucose, hunger/satiety, and energy metabolism returned to baseline. By 240 min, participants reported increased feelings of hunger, and this could have led to overeating at lunch. This study also had a small sample size and the population was not very diverse, which means these results may not apply to the general population. In addition, the small sample size may have limited our ability to find significance in some of the data. Another limitation is the caloric content of the test breakfasts. The NW and OW participants consumed breakfasts with identical caloric values. It could be that the OW participants typically consume breakfasts higher in calories than do the NW participants, which would account for some of the differences observed. Finally, the protein content of the PRO was lower than what has been previously studied. Higher protein meals typically contain 30% of energy from protein. In this study, the PRO contained 22% of energy from protein, which could have been a key factor in the blunted postprandial responses we saw compared with what has been published. Although we were able to demonstrate a significant effect on satiety response, an increase in protein in the test meal may produce a further increase in postprandial energy metabolism and improved glycemic response. Therefore, future studies should assess whether adaptation to a breakfast containing 30% of energy from protein could lead to more robust effects on postprandial energy metabolism.

In conclusion, compared with a CHO, a PRO decreased postprandial hunger and increased satiety in both NW and OW children. There was an increase in postprandial EE and substrate oxidation after consumption of the PRO compared with the CHO, especially in OW children. Taken together, these data suggest that increasing protein and reducing carbohydrate at breakfast could lead to increased satiety and EE, which potentially could lead to weight reduction over time.

Acknowledgments

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References


