A Reduced–Glycemic Load Diet in the Treatment of Adolescent Obesity

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Background: The incidence of type 2 diabetes increases markedly for obese children after puberty. However, the effect of dietary composition on body weight and diabetes risk factors has not been studied in adolescents.

Objective: To compare the effects of an ad libitum, reduced–glycemic load (GL) diet with those of an energy-restricted, reduced-fat diet in obese adolescents.

Design: Randomized control trial consisting of a 6-month intervention and a 6-month follow-up.

Main Outcome Measures: Body composition (body mass index [BMI; calculated as weight in kilograms divided by the square of height in meters] and fat mass) and insulin resistance (homeostasis model assessment) were measured at 0, 6, and 12 months. Seven-day food diaries were used as a process measure.

Subjects: Sixteen obese adolescents aged 13 to 21 years.

Intervention: Experimental (reduced-GL) treatment emphasized selection of foods characterized by a low to moderate glycemic index, with 45% to 50% of energy from carbohydrates and 30% to 35% from fat. In contrast, conventional (reduced-fat) treatment emphasized selection of low-fat products, with 55% to 60% of energy from carbohydrates and 25% to 30% from fat.

Results: Fourteen subjects completed the study (7 per group). The GL decreased significantly in the experimental group, and dietary fat decreased significantly in the conventional group (P<.05 for both). At 12 months, mean±SEM BMI (−1.3±0.7 vs 0.7±0.5; P=.02) and fat mass (−3.0±1.6 vs 1.8±1.0 kg; P=.01) had decreased more in the experimental compared with the conventional group, differences that were materially unchanged in an intention-to-treat model (n=16) (BMI, P=.02; fat mass, P=.01). Insulin resistance as measured by means of homeostasis model assessment increased less in the experimental group during the intervention period (−0.4±0.9 vs 2.6±1.2; P=.02). In post hoc analyses, GL was a significant predictor of treatment response among both groups (R²=0.51; P=.006), whereas dietary fat was not (R²=0.14; P=.22).

Conclusions: An ad libitum reduced-GL diet appears to be a promising alternative to a conventional diet in obese adolescents. Large-scale randomized controlled trials are needed to further evaluate the effectiveness of reduced-GL and –glycemic index diets in the treatment of obesity and prevention of type 2 diabetes.


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50 g of available carbohydrates from a test food, divided by the area under the curve after consuming 50 g of carbohydrates from a reference food, usually white bread or glucose. The GI of a food, meal, or diet is calculated by multiplying the GI by the amount of carbohydrates consumed. One-day feeding studies have consistently reported increased hunger or voluntary food intake in subjects after eating high- compared with low-GI foods. Consumption of high-GI and -GL meals appears to elicit a sequence of hormonal events that limit availability of metabolic fuels in the late postprandial period, leading to excessive hunger and overeating. Short-term treatment studies have described beneficial effects of low-GI or -GL diets on body weight and composition. Slabber et al reported greater weight loss after 3 months among obese women who were counseled to eat low-GI foods compared with those who did not receive this advice. Bouche et al found that fat mass decreased significantly more in overweight men after 5 weeks of a low-compared with a high-GI diet. Spieth et al retrospectively observed a greater reduction in body mass index (BMI; calculated as weight in kilograms divided by the square of height in meters) with a reduced-GL, compared with a reduced-fat diet prescription in children and adolescents who were followed up for an average of 4 months. In addition, 2 large-scale, prospective observational studies found a direct association between GL and risk for type 2 diabetes mellitus, after controlling for the effects of BMI and other potential confounders. However, the long-term efficacy of reduced-GL diets in the treatment of obesity and reduction of diabetes risk factors has not been previously evaluated.

The aims of this work were (1) to develop a reduced-GL diet for use in an adolescent population; (2) to determine whether adolescents following this diet will successfully achieve long-term reduction of GL; and (3) to compare the long-term effects of a reduced-GL diet with those of a conventional reduced-fat diet in a pilot study involving obese adolescents. Development and testing of novel dietary treatment for obesity is arguably of major public health significance, in view of the continuing debate regarding the efficacy of conventional reduced-fat diets for weight control.

**METHODS**

**OVERVIEW OF STUDY DESIGN**

Subjects were randomly assigned to experimental (reduced GL) or conventional (reduced fat) dietary treatment. Both groups received similar behavioral therapy, physical activity recommendations, and treatment intensity. The study, conducted in the General Clinical Research Center of Children’s Hospital Boston, Boston, Mass, consisted of a 6-month intensive intervention (12 dietary counseling sessions) and a 6-month follow-up (2 dietary counseling sessions). Body composition and insulin resistance were measured at 0, 6, and 12 months.

**SUBJECTS**

The protocol was approved by the Institutional Review Board at Children’s Hospital Boston. Written informed consent was obtained from subjects 18 years or older and from the parents of minors; assent was obtained from minors. After screening for study eligibility, 16 obese patients (5 male and 11 female patients; 13 white and 3 nonwhite) aged 13 to 21 years were enrolled and randomized between December 1, 2000, and September 30, 2001 (Figure 1). Obesity was defined as a BMI that exceeded sex- and age-specific 95th percentiles. All subjects were free of major medical illness, as assessed by means of physical examination and screening laboratory tests (measurement of kidney and liver enzymes, thyrotropin, glycosylated hemoglobin, and fasting plasma glucose levels and urinalysis).

**DIET PRESCRIPTIONS**

The reduced-GL prescription emphasized selection of carbohydrate-containing foods (eg, nonstarchy vegetables, fruits, legumes, nuts, and dairy) that are characterized by a low to moderate GI. Patients were instructed to balance consumption of carbohydrates with protein and fat at every meal and snack. The prescription was not energy restricted. Rather, subjects were advised to eat to satiety and to snack when hungry. The targeted proportion of energy from carbohydrate and fat were 45% to 50% and 30% to 35%, respectively, with the remainder from protein. An ad libitum approach was used in light of preliminary evidence that suggests greater satiety and decreased voluntary energy intake occurs among children and adolescents consuming reduced-GL diets.

The reduced-fat prescription was based on current recommendations for weight loss and diabetes prevention, with emphasis on limiting dietary fat intake and increasing the intake of grains, vegetables, and fruits. Meal plans were designed to elicit a negative energy balance of 250 to 500 kcal/d. Energy requirements were estimated using the Harris-Benedict equation, with an activity factor of 1.5 and consideration of baseline dietary intake. Subjects were counseled to obtain 55% to 60% of energy from carbohydrates, 25% to 30% from fat, and the remainder from protein.

**NUTRITION EDUCATION AND BEHAVIORAL THERAPY**

Social cognitive theory provided a conceptual framework for the educational and behavioral components of treatment that was consistent between intervention groups. Counseling focused on enhancing self-efficacy for dietary change using the concepts of behavioral capability (knowledge and skill) and self-control. Patient expectations (anticipated outcomes), expectations (values ascribed to outcomes), and perceptions of environmental influences were discussed during treatment sessions.

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**Figure 1.** Trial design. GL indicates glycemic load.
Written materials included topic modules, food choice lists, and a select-a-meal menu. The topic modules were the primary mechanism for presenting nutrition intervention messages and facilitating self-assessment, goal setting, and problem solving. These modules were designed to promote dialogue between the patient and study dietitian. Food choice lists were used to enhance practical application of intervention messages presented in the topic modules. For the experimental group, lists corresponded to food groups delineated by a reduced-GL food pyramid. In contrast, for the conventional group, the lists corresponded to the diabetes food pyramid and were presented as an exchange system. The select-a-meal menu contained recipes and ideas for meal planning to complement the food choice lists. One topic module was devoted to physical activity, with subjects in both groups receiving information based on current recommendations. Nutrition bars were offered to subjects in the experimental (Balance Bar; kindly provided by Kraft Foods, Inc, Northfield, Ill) and conventional groups (Nature Valley Granola Bar; General Mills, Inc, Minneapolis, Minn) for occasional use as snacks.

PROCESS EVALUATION

The treatment process was evaluated from the perspectives of interventionist adherence to nutrition education and counseling protocols, and subject participation and adherence to diet prescriptions.

Interventionist adherence may be conceptualized as treatment fidelity, a term encompassing integrity and differentiation. Integrity is the degree to which treatment is implemented according to established procedures, and differentiation is the extent to which interventions are distinct from one another. Several strategies were used to maximize treatment fidelity in the present study. First, written materials for the experimental and conventional groups were developed specifically for the pilot study such that the format and quality were completely parallel. The materials differed only with regard to the specific intervention messages pertaining to GL and dietary fat. Second, the interventionist was a dietitian (M.M.L.) trained in the science underlying each intervention and given precise instructions regarding use of written materials to ensure differentiation of the intervention messages. Third, to prevent shifts in implementation, the dietitian completed a tracking form and progress note immediately after each session. The project director (C.B.E.) met with the study dietitian on a regular basis to review tracking forms and progress notes and to discuss treatment of individual subjects.

Subject participation was evaluated on the basis of session attendance, and adherence was assessed by means of self-report of dietary intake. All subjects received extensive instruction and practice in keeping food diaries. Three-dimensional food models, plates, bowls, glasses, and measuring cups and spoons were used to educate them regarding accurate appraisal of portion sizes. The diaries were reviewed with the subject at the time of receipt to obtain clarification, as necessary, on recorded foods and beverages. Food Processor Plus software (Version 7.9; ESHA Research, Salem, Ore) was used to quantify intakes of fat, carbohydrate, protein, and fiber. The GI of individual foods was assigned according to published values. We calculated the GI by multiplying the total gram amount of dietary carbohydrate by the weighted GI for each food and then adjusted for energy intake using the following equations: weighted GI = \( \sum (\text{GI for food item} \times \text{portion of total carbohydrate contributed by item}) \), and GL = (weighted GI \times grams of carbohydrate)/1000 kcal. Data from 7-day food diaries were used to evaluate process outcomes at baseline, during the intervention period (months 3 and 6), and at the end of the follow-up (month 12).

In addition, self-monitoring of food intake was encouraged throughout the intervention period to enhance self-control and facilitate problem solving. The study dietitian reviewed self-reported intake after each individual counseling session to identify deviations from diet prescriptions and made corrective recommendations to the subject when necessary.

ASSESSMENT OF STUDY OUTCOMES

Total body mass and fat mass were measured by dual-energy x-ray absorptiometry using Hologic instrumentation (Model QDR 4500; Hologic, Inc, Bedford, Mass). Height was measured using a wall-mounted stadiometer (Holtain Limited, Crymych, Wales). A blood sample was drawn by means of venipuncture after a 12-hour overnight fast. Plasma glucose level was measured using a Hitachi analyzer (Model 917; Roche Diagnostics, Indianapolis, Ind), and serum insulin level was measured using an Elecsys system (Model 2010; Roche Diagnostics). We used homeostasis model assessment (HOMA) to estimate insulin resistance by means of the following equation: (fasting serum insulin level [in microunits per milliliter] \times fasting plasma glucose level [in millimoles per liter])/22.5. This index has been used previously for assessing insulin resistance in youth, with higher values indicating lower insulin sensitivity.

STATISTICAL METHODS

We conducted statistical analyses using SAS software (Release 8.2; SAS Institute Inc, Cary, NC). Repeated-measures analysis of variance was performed using the mixed linear model procedure. Component contrasts were estimated from the fitted model for preplanned comparisons (within treatment group changes over time and differences between groups for changes over time). The time intervals of interest were 0 to 6 months and 0 to 12 months. Data from all subjects who completed the study (n=14) were included, irrespective of their level of adherence. Change in insulin resistance was adjusted for change in BMI. Secondary intention-to-treat analyses of body composition end points were performed for all randomized subjects (n=16), assuming no change from baseline for the 2 subjects who were lost to follow-up (1 refused to return; 1 began medication known to affect body mass, an exclusionary criterion). Results are presented as mean±SEM.

We conducted simple linear regression (using the general linear models procedure), pooling data from both groups, to explore whether changes in dietary GL or fat intake (average of values obtained at 3 and 6 months) independently predicted change in body fat. When exploring relationships between dietary variables and body fat, we eliminated 1 outlier from regression analyses, although data from this outlier are displayed. The outlier was a young woman who matriculated in medical school during participation in the study. On the basis of previous research, we speculated that apparent underestimation of dietary intake by this subject may be attributed, in part, to expression of a social desirability bias.

RESULTS

PROCESS DATA AND BASELINE CHARACTERISTICS

Fourteen subjects finished the study (7 per group), yielding a completion rate of 87.5%. There were no group differences in session attendance, with subjects in the experimental and conventional groups completing 9.4±0.6 of the 12 planned sessions during the intervention pe-
All 14 subjects attended the 2 scheduled sessions during the follow-up.

At baseline, we found no differences between the experimental and conventional groups for age (16.9±1.3 vs 15.3±0.9 years; \( P = .33 \)), body mass (103.5±6.0 vs 104.7±4.8 kg; \( P = .88 \)), height (171.6±3.3 vs 167.9±2.1 cm; \( P = .37 \)), BMI (34.9±1.0 vs 37.1±1.2; \( P = .21 \)), and HOMA estimation of insulin resistance (3.5±0.7 vs 4.3±0.7; \( P = .43 \)). However, fat mass was lower for the experimental group compared with the conventional group (38.8±2.6 vs 48.5±3.0 kg; \( P = .03 \)).

Changes in dietary variables are presented in the Table. The GL decreased for the experimental group (0-6 months, \( P = .005 \); 0-12 months, \( P = .007 \)) and did not change significantly for the conventional group. Dietary fat decreased for the experimental group (0-6 months, \( P = .01 \); 0-12 months, \( P = .03 \)) and tended to increase for the experimental group (0-6 months, \( P = .06 \)). Carbohydrate intake decreased for the experimental group (0-6 months, \( P = .03 \); 0-12 months, \( P = .07 \)).

### STUDY OUTCOMES

As shown in Figure 2, BMI (\( P = .03 \)) and fat mass (\( P = .02 \)) decreased in the experimental group from 0 to 12 months, and neither outcome changed significantly in the conventional group. At 12 months, BMI (−1.3±0.7 vs 0.7±0.5; \( P = .02 \)) and fat mass (−3.0±1.6 vs 1.8±1.0 kg; \( P = .01 \)) had decreased significantly more in the experimental compared with the conventional group. These results were materially unchanged in intention-to-treat analyses (BMI, −1.2±0.7 vs 0.6±0.5; \( P = .02 \); fat mass, −2.6±1.5 vs 1.6±0.9 kg; \( P = .01 \)). Of interest, there was no weight regain between 6 and 12 months for the experimental group. Insulin resistance, as assessed by means of HOMA, increased significantly less in the experimental compared with the conventional group during the intervention period (−0.4±0.9 vs 2.6±1.2; \( P = .02 \)), and statistical adjustment for BMI did not materially alter this result (\( P = .03 \)).

### DIETARY VARIABLES AS PREDICTORS OF CHANGE IN BODY FAT

Figure 3 depicts results of bivariate linear regression analysis, using dietary GL or fat intake during the intervention period as the independent variable and change in body fat from 0 to 6 months as the dependent variable. Changes in dietary GL were a strong predictor of this study outcome, explaining about half of the variance in both groups combined (\( R^2 = 0.51 \); \( P = .006 \)). In contrast, change in dietary fat was not significantly associated with change in body fat (\( R^2 = 0.14 \); \( P = .22 \)).

**Comment**

Treatment of obesity in adolescents is characterized by modest weight loss and substantial relapse.5 Virtually no studies in this age range have sought to examine the in-

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### Table

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**Abbreviations:** GI, glycemic index; GL, glycemic load.

*Data are expressed as mean ± SEM.

†\( P < .05 \), significantly different from baseline.

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fluence of dietary composition per se on body weight. In this pilot study, we investigated the independent effects of an experimental reduced-GL diet vs a conventional reduced-fat diet, using similar behavioral strategies, physical activity prescriptions, and treatment intensity in both groups. Although both groups showed the intended changes in targeted dietary factors, measures of adiposity decreased significantly more in the reduced-GL group. This result is of particular interest, in that the reduced-GL diet was prescribed in an ad libitum fashion, whereas the reduced-fat diet was energy restricted, consistent with conventional practices. Subjects receiving the reduced-GL diet may have felt less hunger and/or greater satiety, facilitating reduced energy intake and allowing for weight loss to occur without an externally imposed energy restriction. The potential flexibility of such a diet may have particular behavioral benefits for adolescents who have a strong desire for autonomy. During focus groups, teenagers mentioned not wanting to be told what to do as a barrier to participating in family meals. The lack of a strict energy restriction may help to prevent tension between adolescents who are ambivalent regarding dietary change and adults who want to support change. In a previous study, children with type 1 diabetes mellitus were more easily able to select their own foods when prescribed a low-GI diet compared with a regimented meal plan based on an exchange system without consideration for GI. They also achieved better glycemic control, while experiencing less family conflict, with the low-GI diet. At the end of the study, children expressed an overall preference for the low-GI diet compared with the regimented plan.

We also examined insulin resistance, as prevention of type 2 diabetes mellitus is a primary goal of obesity treatment in adolescents. Insulin resistance, as assessed by means of HOMA, increased significantly in the reduced-fat group, possibly owing to the increase in insulin resistance that occurs with progression through puberty. In contrast, insulin resistance did not change in the reduced-GL group. Moreover, the group effect remained significant after adjustment for change in BMI. These findings are consistent with epidemiological data that show lower risk for diabetes among individuals consuming a low-GL diet, after controlling for BMI. Thus, reducing dietary GL may protect against diabetes through weight-dependent and weight-independent mechanisms, as previously hypothesized.

Adherence to diet prescriptions, regardless of group assignment, was likely affected by intrapersonal, interpersonal, and environmental influences. Not surprisingly, motivation varied widely, with some adolescents showing a strong desire to change their eating behaviors to lose weight and others demonstrating very little concern about their weight status. Although most participating parents were well intentioned, not all provided adequate support with regard to provision of recommended foods, transportation to counseling sessions, and encouragement. Adolescents who participated in the pilot study often enjoyed socializing with peers at food courts and fast-food restaurants, where they were challenged to make reduced-GL or reduced-fat food choices. Research is needed to develop novel strategies for motivating obese adolescents to change their eating behaviors and for motivating parents to provide appropriate support in environments that pose challenges to adherence.

Several issues pertaining to study design should be noted. Strengths of the study include careful attention to treatment fidelity, a well-defined conceptual framework to promote behavior change, a relatively long follow-up, and high subject retention. Study limitations include a small sample size and reliance on self-report for dietary assessment. Underreporting of energy intake is a recognized source of measurement error when assessing adolescent diets. Adjusting other dietary variables

Figure 3. Changes in dietary glycemic load (GL) or fat intake as predictors of change in body fat. One outlier (indicated by the circled data point) was excluded when calculating regression lines (solid) and 95% confidence intervals (dashed). Black circles indicate subjects in the experimental group; white circles, subjects in the conventional group.
Adolescent obesity increases the risk for a wide range of serious complications, including type 2 diabetes mellitus. Given the current obesity epidemic, novel treatment strategies are needed urgently. No previous studies have evaluated the effects of diet composition per se on treatment outcomes in obese adolescents. The results of this study indicate that a reduced-GL diet may yield greater benefits than a conventional reduced-fat diet. These pilot data, derived from a relatively long-term intervention study, provide strong rationale for conducting large-scale randomized controlled trials to evaluate the effectiveness of a reduced-GL diet in the treatment of obesity and prevention of diabetes mellitus. This line of investigation has the potential to change clinical practice and public health guidelines.

for energy intake may partially correct for underreporting, although differences in the accuracy of self-report among foods is not well understood.46 Study findings may be confounded by the baseline group difference in fat mass despite randomization; however, there is no a priori reason to believe that subjects in the experimental group, who had lower fat mass at baseline than their counterparts in the conventional group, would lose more absolute body fat. Furthermore, we cannot definitely attribute treatment effects exclusively to changes in GL, as other dietary factors such as fiber or palatability may mediate or confound the relationship between changes in GL and changes in adiposity to some degree (an issue in all long-term outpatient dietary studies).

CONCLUSIONS

Our results suggest that reducing dietary GL may have greater benefits than reducing dietary fat when treating adolescent obesity to lower the risk for type 2 diabetes mellitus. Although findings must be considered preliminary, this study provides relevant pilot data to inform future research. Large-scale randomized controlled trials are needed to evaluate the effectiveness and public health applications of reduced-GL and -GI diets.

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