American Dietetic Association

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Research and Professional Briefs

A High-Sugar/Low-Fiber Meal Compared with a Low-Sugar/High-Fiber Meal Leads to Higher Leptin and Physical Activity Levels in Overweight Latina Females

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ABSTRACT

Acute effects of high-sugar/low-fiber meals vs low-sugar/high-fiber meals on hormones and behavior were studied in 10 overweight Latina females, age 11 to 12 years, using a crossover design. In this exploratory pilot study, participants arrived fasted at an observation laboratory on two occasions and randomly received either a high-sugar/low-fiber meal or a low-sugar/high-fiber meal at each visit. Glucose, insulin, and leptin were assayed from serum drawn at 0, 15, 30, 60, 90, and 120 minutes. Ad libitum snacks were provided at 120 minutes. Physical activity was measured using an observational system that provides data on time spent lying down, sitting, standing, walking, and in vigorous activity. Data were collected between March 2005 and July 2006. In the high-sugar/low-fiber condition, glucose and leptin levels decreased more slowly, glucose levels were higher at 60 minutes (111.2 mg/dL vs 95.4 mg/dL, P=0.03), and leptin levels were higher at 90 minutes (49.3 ng/mL vs 46.7 ng/mL, P=0.017) than in the low-sugar/high-fiber condition. Meals did not affect insulin or ad libitum dietary intake. Sitting, standing, lying down, and vigorous activity differed by condition, but not walking. Participants were significantly more active in the first 30 to 60 minutes after the high-sugar/low-fiber meal, but after 60 minutes there was a trend for activity to be lower after the high-sugar/low-fiber meal vs the low-sugar/high-fiber meal. High-sugar meals sustain glucose and leptin levels longer, which may play an important role in modulating levels of physical activity in this group at high risk for obesity-related disease.

J Am Diet Assoc. 2009;109:1058-1063.

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Manuscript accepted: December 12, 2008.

0002-8223/09/10906-0010$36.00/0
doi: 10.1016/j.jada.2009.03.013

Pediatric obesity has reached epidemic proportions, particularly among Hispanic and African-American youth (1), placing them at high risk for type 2 diabetes (2) and other diseases (3,4). Physical activity is central to the prevention and treatment of obesity. Unfortunately, physical activity levels decrease sharply during adolescence (5-7), particularly in girls (8). This decrease is especially profound in Hispanic females (9).

The diet of Hispanic children is particularly high in total energy and added sugar (10,11). Food consumption stimulates leptin secretion after the meal (12,13), and high-carbohydrate meals result in greater leptin responses (14). Chronically augmented leptin may be an independent causal factor in the development of leptin resistance (15). Compared with adolescent boys, adolescent girls may be at even greater risk for leptin insensitivity because of higher basal leptin concentrations (16,17).

High–simple carbohydrate meals are frequently low in fiber and have been associated with poor glycemic control (18-21), poor mood, feelings of fatigue, and low levels of physical activity postprandially and over time (22,23). In adults, a simple-carbohydrate breakfast resulted in higher glucose and insulin levels than a complex-carbohydrate breakfast. Subjects who consumed the complex-carbohydrate breakfast reported higher satiety, better mood, and lower feelings of fatigue (24). In adults, low fiber intake has been related to negative mood and depression (25). Diets rich in sucrose have been shown to increase postprandial leptin (26); however, these higher postprandial leptin levels were not related to postprandial satiety or food intake (14). High-sugar/low-fiber meals may, therefore, play a dual role in the current obesity epidemic: one, by increasing energy intake and affecting leptin's ability to serve as an effective satiety signal, and two, through the possible negative effects of sugar consumption on physical activity levels.

Earlier acute feeding studies in children have examined the effect of different meals on insulin and glucose metabolism, glucagon, fatty acids, epinephrine, satiety, and ad libitum food intake (27-30). To date, no studies have examined the acute effect of meal type on either physical activity or on hormones that are related to both feeding behaviors and physical activity, such as leptin (16). Therefore, in this study of the effects of high-sugar/low-fiber vs low-sugar/high-fiber meals in Latina females, the hypotheses were that: (a) plasma levels of glucose, insulin, and leptin would be higher after the high-sugar/low-fiber meals and take longer to return to baseline, and (b) girls would be less physically active and consume higher amounts of food ad libitum after the high-sugar/low-fiber meal.

METHODS

Overview

An acute feeding study was used to study the effects of a high-sugar/low-fiber meal vs a low-sugar/high-fiber meal on plasma levels of glucose, insulin, and leptin, and objectively measured physical activity in overweight Latina girls. Participants were recruited from the Women's and Children's Hospital, surrounding sports clubs, and after-school venues. Inclusion criteria were: female sex, 11 to 13 years of age, body mass index (BMI) more than or equal to the 95th age- and sex-specific percentile (23), and parents and all four grandparents were of Latino origin as determined by parents' self-report. Participants visited an observation laboratory twice (crossover design) and received one of the experimental meals (order of meal visits was randomized).

Screening

Participants completed a standard oral glucose tolerance test to preclude diabetes (31) at the University of Southern California General Clinical Research Center. Weight and height were measured using a beam medical scale and wall-mounted stadiometer. BMI age- and sex-specific percentiles (32) were determined using EpiInfo (version 1.1, 2000, Centers for Disease Control and Prevention, Atlanta, GA). Body fat was measured by dual-energy x-ray absorptiometry using a Hologic QDR 4500 densitometer (Hologic, Inc, Bedford, MA). Parents and participants provided consent/assent after being informed that this study examined the effects of food on mood and behavior and that participants would be videotaped throughout their stay in the Observation Laboratory. Procedures were approved by the University of Southern California Institutional Review Board.

Procedures

Participants visited the Observation Laboratory after a 12-hour fast on two separate mornings with at least 2 weeks between visits. Participants received a high-sugar/low-fiber cereal meal at one visit and a low-sugar/high-fiber cereal meal at the other visit (in random order). High-sugar/low-fiber meals had 488 calories (18% of calories from fat, 70% from carbohydrate, and 14% from protein), 63.66 g of sugar (52.18%), and 0.76 g of fiber (0.62%). Low-sugar/high-fiber meals had 491 calories (19% of calories from fat, 70% from carbohydrate, and 18% from protein), 35.63 g of sugar (29%), and 17.66 g of fiber (14.4%). The laboratory was outfitted with a treadmill, jump ropes, hula hoops, a small trampoline, *Dance Dance Revolution* (Konami, Tokyo, Japan) active computer game, and collections of movies, music compact discs, books, magazines, and comic books. A saline lock was placed on the nondominant arm in the same location each visit, generally in the antecubital fossa. Blood was drawn at baseline (5 minutes prior to the meal). Participants were given 15 minutes to complete breakfast. Subsequent blood draws occurred at 15, 30, 60, 90, and 120 minutes from the start of the meal. After breakfast, participants were invited to choose whatever activities they preferred in the laboratory for 2 hours. The entire session was videotaped. The ad libitum snack, including sandwiches, chips, cookies, and a choice of drinks (sodas, juice, and milk), was provided after the last blood draw. Data were collected from March 2005 to July 2006.

Nutrient Data System (NDS-R version 5.0_35, 2005, University of Minnesota, Minneapolis) was used to calculate nutrient intake from plate waste. Glucose was assayed using a Yellow Springs Instruments analyzer (Yellow Springs Instrument, Yellow Springs, OH). Insulin was assayed by enzyme-linked immunosorbent assay (ELISA) using a Tosoh AIA 600 II Immunoassay Analyzer (Gibbco Scientific, Inc, Coon Rapids, MN), and leptin was assayed by ELISA kit (Linco, Inc, St Charles, MO). To estimate general levels of physical activity, participants wore Walk4Life pedometers (Plainfield, IL) for 6 to 7 days before their first laboratory visit. Trained observers blinded to the research condition analyzed the videotapes of each 2-hour laboratory visit using NOLDUS Observer XT software (version 5.0, Noldus Information Technology, Leesburg, PA) programmed to score physical activity levels according to the System for Observing Fitness Instruction Time (SOFIT) (33). SOFIT scores five categories of behavior (lying down, sitting, standing, walking, and vigorous activity). For this study, SOFIT was adapted by eliminating the 20-second observe/record intervals and implementing continuous observation and real-time behavior scoring to obtain Continuous Observation scores (SOFITCO). Activity was summed over time periods between blood draws to create increments for analyses. The original five SOFIT categories were enhanced by continuous coding of fidgeting, thus including non-exercise activity thermogenesis (NEAT) using a set of conventions developed by Levine (34). NEAT includes activities other than exercise, sports, and fitness-related activities. Of interest here was the inclusion of fidgeting.

Inter-rater reliability for four raters using the SOFITCO system was 0.814 ($P<0.0001$) (35).

Statistical Analyses

Means, standard deviation, and standard errors were generated. Longitudinal generalized linear mixed effects modeling (GLMM) was used to examine meal differences in hormones and behavior at specific time points and across time. GLMM allows for specification of fixed and random effects of variables on levels as well as change over time. The GLMM models were constructed to allow for the modeling of nonlinear trends across the 2-hour observation period. Models controlled for visit order as a covariate to correct for possible effects of familiarity with the surroundings at the second visit regardless of meal type. Analyses were conducted in SPSS (version 13.0, 2004, SPSS Inc, Chicago, IL), and type 1 error was set at $\alpha<0.05$. Because the study was not sufficiently powered to test for significant differences, the goal was to describe group differences.

RESULTS AND DISCUSSION

Participant Characteristics

Participants were 10 Latina females, mean age (±standard deviation) 12.1±0.7 years, at or over the 95th BMI percentile. Mean total body fat was 41.9%±3.3%. Although guidelines for healthy percentage of body fat in children have yet to be developed, this is considered high even in adult populations (36). Mean fasting glucose was 90.3±3.6 mg/dL, mean fasting insulin was 16.9±10.1 Uu/mL, and mean fasting leptin was 52.6±22.1 ng/dL. Participants took a mean of 5,728±3,682 steps per day. Thus, this sample had considerably higher leptin levels (37) and lower physical activity levels measured by pedometer (steps per day) (38) in comparison with other samples of overweight children.

Breakfast and Ad Libitum Snack Consumption

On average, participants consumed 62% of breakfast. There were no significant differences in amount eaten between the low-sugar/high-fiber and high-sugar/low-fiber conditions. Between the two conditions, there were no differences in ad libitum energy or nutrient intake at 2 hours after breakfast.

Glucose, Insulin, and Leptin

Blood glucose levels were equal at −5 minutes, but decreased significantly more slowly in the high-sugar/low-fiber condition than in the low-sugar/high-fiber conditon from 30 to 60 minutes ($P=0.026$) and from 60 to 120 minutes ($P=0.017$). At 60 minutes, total glucose was thus significantly higher for the high-sugar/low-fiber than the low-sugar/high-fiber meal condition (mean 111.2 mg/dL [6.2 mmol/L] vs 95.4 mg/dL [5.30 mmol/L], $P=0.03$; Figure 1, top panel). This slower glucose decrease from 30 to 60 minutes and higher glucose levels in the high-sugar/low-fiber condition at 60 minutes corresponded in time to both higher physical activity levels and higher leptin levels as discussed later.

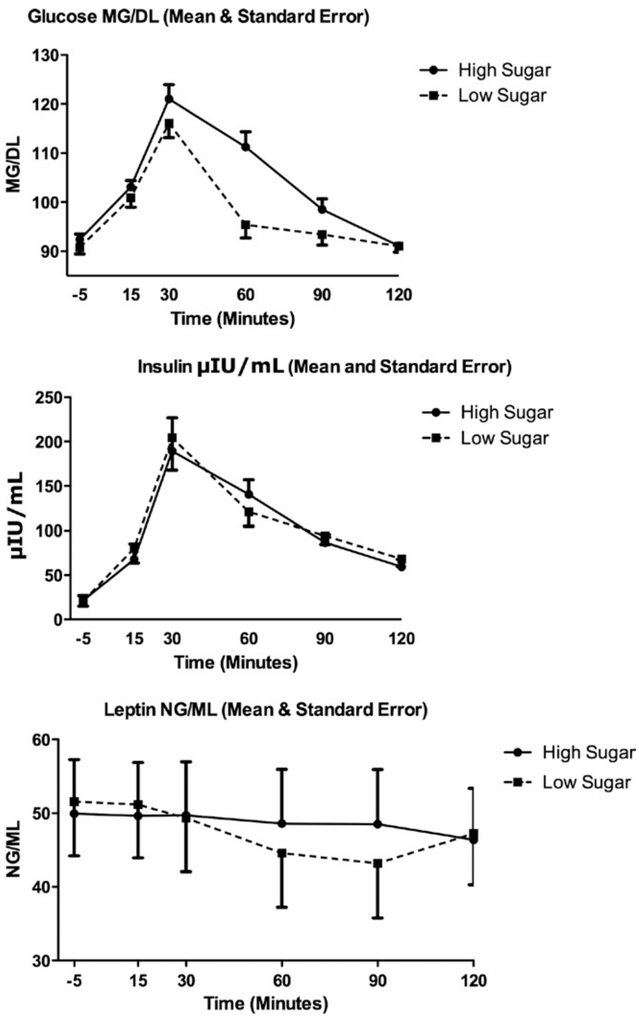

Figure 1. Overweight Latina girls show higher glucose levels and slower clearance (top panel), no differences in insulin levels (middle panel), and higher leptin levels and slower clearance (bottom panel)* after a high-sugar meal as opposed to a low-sugar meal. *Effect of meal over 120 minutes controlling for visit.

There was no significant effect of meal type on insulin levels or in rate of change between any timepoints over the two hours (Figure 1, middle panel), which was surprising in light of earlier studies that have found meal effects on insulin levels (29). It is unclear what caused the slower decrease in glucose levels in the high-sugar/low-fiber group because it was not associated with higher insulin levels. This might imply an acute change in relative insulin resistance, without the expected compensatory hyperinsulinemia, after the high-sugar/low-fiber meal. Alternatively, this finding could reflect an acute decrease in glucose effectiveness, the ability of glucose to reduce its own concentration independent of insulin (eg, by reducing hepatic glucose production) (39) brought on by the high-sugar/low-fiber vs low-sugar/high-fiber meal. Although participants were already quite insulin-resistant, as indicated by baseline fasting insulin levels, it is possible that, relative to the increase in glucose after the high-sugar/low-fiber meal, the insulin response is inadequate or stunted. This could indicate that the beta-cell secretion has reached a "ceiling effect," maximizing at the observed levels. Alternatively, this could indicate a difference between the two meals in insulin secretogogues other than glucose. This might be due to the high-sugar/low-fiber vs low-sugar/high-fiber difference in percentage protein (40), or different incretin responses (eg, glucagon-like peptide 1 [GLP-1]) to high-sugar/low-fiber vs low-sugar/high-fiber meals (41).

Changes in plasma leptin followed a different time-course during the first 90 minutes between conditions. There was a neglible post-prandial decline in plasma leptin following the high-sugar/low-fiber meal, whereas the low-sugar/high-fiber meal was accompanied by a significant decrease in leptin compared to the high-sugar/low-fiber meal (Figure 1, bottom panel), (slope, −5 to 90 minutes, $P=0.026$). There was also a significant difference in leptin levels at 90 minutes (low-sugar/high-fiber vs high-sugar/low-fiber; mean, 46.7 vs 49.31 ng/mL, $P=0.017$). During the last 30 mintues, there were no significant differences between the two meals. Postprandial suppression of leptin was diminished after high-sugar/low-fiber meal, leading to higher leptin levels at 90 minutes, but there were no differences in subsequent ad libitum food intake. It has been suggested that overweight children may have deficient satiety signaling or be less responsive to satiety signals (37). Baseline leptin was also quite high in this group of overweight girls. Elevated leptin concentrations may be critical in the development of leptin resistance. Both rodent and human models of obesity demonstrate increased leptin levels that increase proportionally with increased adiposity, yet fail to halt the progression of obesity (42-44).

Physical Activity

Girls in the low-sugar/high-fiber condition spent more time sitting during the 30- to 60-minute block after the meal ($P=0.016$), but time spent sitting in this condition decreased from 60 to 90 minutes whereas time spent sitting increased in the high-sugar/low-fiber condition, resulting in a significant interaction in condition (meal) by time at 120 minutes ($P=0.049$) (Figure 2, top panel). Minutes spent standing after the high-sugar/low-fiber meal was significantly higher during the 30- to 60-minute block ($P=0.025$, high-sugar/low-fiber vs low-sugar/high-fiber). However, between 60 to 120 minutes, minutes spent standing decreased after the high-sugar/low-fiber meal, while increasing after the low-sugar/high-fiber meal ($P=0.040$ for slope over 60 to 120 minutes in high-sugar/low-fiber vs low-sugar/high-fiber) (Figure 2, middle panel). There were no meal effects on walking. Time spent in lying down differed only at the 90- to 120-minute block, during which girls in the low-sugar/high-fiber condition spent more time lying down ($P=0.019$) (data not shown). In the 30- to 60-minute block, girls exhibited more vigorous activity in the high-sugar condition ($P=0.05$). Although not significant, it appears in Figure 2, bottom panel that vigorous behavior decreased in the high-sugar condition and increased in the low-sugar condition after the 60-minute mark.

Participants were more active after a high-sugar/low-fiber meal in the first 30 to 60 minutes after the meal, as indicated by increased standing and vigorous activity and decreased sitting. However, after 60 to 90 minutes, there was a trend for activity to be lower after the high-sugar/low-fiber meal vs the low-sugar/high-fiber meal. Concurrent with the high-sugar/low-fiber activity burst during the first 30 to 60 minutes, glucose and leptin levels were elevated in high-sugar/low-fiber vs low-sugar/high-fiber condition. This finding is in agreement with some studies, but not with others. For instance, in one study of 123 5-year-old Pima Indian children (67 boys/76 girls), fasting leptin concentrations were positively related to physical activity levels ($r=0.26$, $P<0.01$) (45); however, in another study, a sample of 253 healthy girls and 257 healthy boys age 8 to 18 years, fasting leptin was higher in girls compared with boys, negatively correlated to number of steps per day as measured by the Yamax Digiwalker pedometer (Walk4Life, Plainfield, IL) in girls ($P<0.001$), and unrelated to physical activity in boys (16).

A limitation to this study was the short (2-hour) time period during which physical activity and hormones were

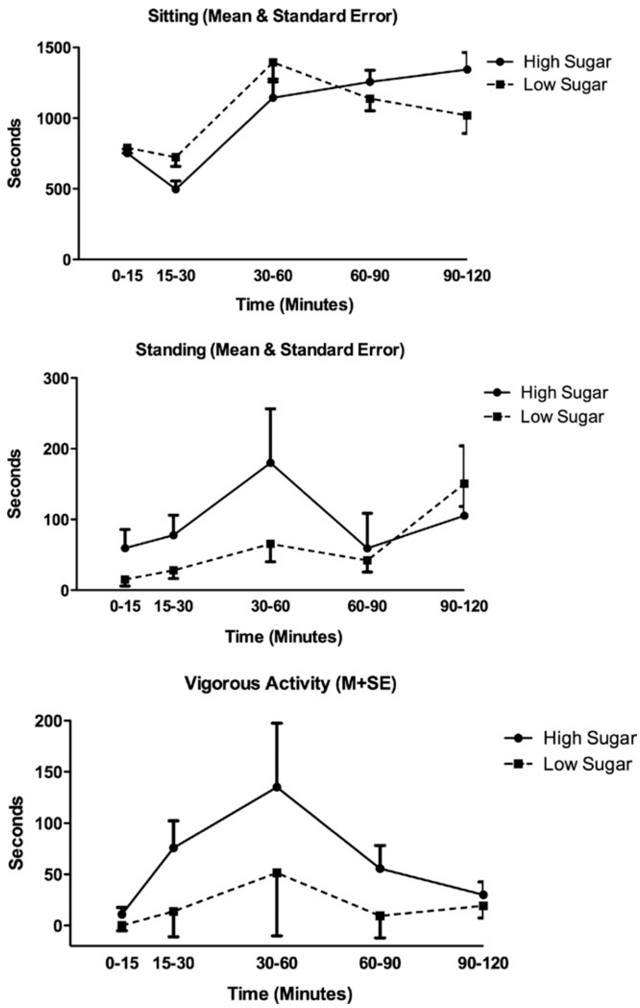

Figure 2. Overweight Latina girls sit less (top panel), stand more (middle panel), and show more vigorous activity (bottom panel) for the first 30 to 60 minutes after a high-sugar meal than after a low-sugar meal.

measured, which may be too short to assess the effect of meal type on ad libitum food consumption (29). Although other micronutrients were comparable between the two meals, the low-sugar/high-fiber meal had a higher percentage of protein, which may have influenced outcomes. Participants had been informed about the purposes of the research and knew that they were being filmed. This may have influenced their behavior, but the randomization of the meal type and statistical control for visit order should account for any systematic variation. However, the fact that participants were being filmed in a laboratory environment limits generalizability. Another limitation was the small sample size. Therefore, this study is currently being replicated in a large sample including multiple ethnicities, different age groups, both sexes, and a 5-hour post-meal observation period.

CONCLUSIONS

A recent study of 707 female (46) and 567 male (47) students, age 13 to 18 years, attending Los Angeles schools found that one of the main reasons that adolescents drank sugar-laden sodas was to experience what they identified as a highly valued "sugar rush." This study suggests that there might be a relative "sugar rush" in physical activity levels, followed by a "crash." This is the first study to examine the difference between two types of meals, high and low in sugar, on spontaneous physical activity and hormones that play a role in the regulation of both food intake and physical activity. These data suggest that meal composition influences glucose, leptin, and physical activity in preadolescent overweight Latinas. Meal composition may thus have an important role in modulating levels of physical activity in this group at high risk for obesity-related disease.

STATEMENT OF POTENTIAL CONFLICT OF INTEREST: No potential conflict of interest was reported by the authors.

FUNDING/SUPPORT: This research was supported by the Donald E. and Delia B. Baxter Foundation, the National Cancer Institute (NCI) Centers for Transdisciplinary Research on Energetics and Cancer (TREC) (U54 CA 116848), the USC Cancer Control and Epidemiology Research Training Grant (NCI T32 CA09492), resources made available to the USC General Clinical Research Center (GCRC) Program by National Institutes of Health (NIH) National Center for Research Resources (NCRR) (MOI RR00043).

ACKNOWLEDGEMENTS: The authors thank Ana Romero, who assisted in all aspects of the study.

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