Relation of dietary glycemic index, glycemic load, added sugar intake, or fiber intake to the development of body composition between ages 2 and 7 y¹⁻³

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ABSTRACT
Background: Observational studies in adults suggest that a diet with a high glycemic index (GI) or glycemic load (GL), a high intake of sugary foods, or a low fiber intake may increase the risk of overweight.

Objectives: We aimed to examine prospectively whether dietary GI, GL, added sugar intake, or fiber intake between age 2 and 7 y are associated with the development of body composition. If so, we aimed to ascertain whether these associations are modified by meal frequency.

Design: Linear mixed-effect regression analyses were performed in 380 participants of the DOrt mund Nutrition and Anthropometric Longitudinally Designed (DONALD) Study for whom 4–6 weighed 3-d dietary records and anthropometric data were obtained between ages 2 and 7 y.

Results: Changes in dietary GI, GL, or added sugar intake between ages 2 and 7 y were not associated with concurrent changes in percentage body fat (%BF, as estimated from skinfold thicknesses) or body mass index SD scores. An increase in fiber intake was related to a concurrent decrease in %BF between ages 2 and 7 y only in children who consumed ≤6 meals/d as toddlers (β ± SE from fully adjusted model: −0.26 ± 0.09%BF per 1-SD increase in fiber intake, P = 0.005), whereas children with a higher meal frequency had no concurrent change (0.07 ± 0.07%BF per 1-SD increase in fiber intake, P = 0.3).

Conclusions: Dietary GI, GL, or added sugar intake between ages 2 and 7 y does not appear to influence the development of body composition. Potential benefits associated with increasing fiber intake throughout childhood may be limited to toddlers with a lower meal frequency. 


INTRODUCTION

Prenatal and early postnatal dietary influences on the development of body composition in childhood recently received increasing attention (1). In addition, nutritional intake during the toddler years (ages 2–4 y) may be critical for the development of body composition throughout childhood, because children undergo the transition from a relatively high intake of fat in early childhood to a relatively high intake of dietary carbohydrates at this time (2). The latter pattern is maintained throughout the remainder of childhood and adolescence (3).

A higher carbohydrate intake could potentially lead to a higher dietary glycemic index (GI) or a higher dietary glycemic load (GL) (or both), each of which has been proposed to contribute to the development of obesity (4). Further aspects of carbohydrate quality that have been implicated in obesity development include intakes of sugary foods and dietary fiber (5, 6). In fact, most (7–11) but not all (12) longitudinal observational studies in adults have shown that the dietary GI and fiber intake are prospectively associated with measures of obesity. Whereas higher sucrose intakes do not appear to exert detrimental prospective effects (13, 14), a high consumption of soft drinks appears to adversely affect the development of body composition in both adults and children (6), which suggests a potential role for added sugars. Should any of these associations also be of relevance in early childhood, a habitually high dietary GI, GL, or added sugar intake or a habitually low dietary fiber intake (or all) may program a person toward greater body fat starting in the toddler years. However, prospective evidence to date for the role of carbohydrate quality in the development of body composition in early childhood is virtually absent.

A higher meal frequency has been proposed to beneficially affect body composition (15) and satiety (16) via a lower postprandial insulin and glucose response (17). It is thus intriguing to consider that meal frequency may influence the association of dietary factors known to affect postprandial insulin and glucose concentrations with caloric intake, body composition, or both. We have, in fact, shown in toddlers and children aged 2, 4–5, and 7 y that the associations between the breakfast dietary GI and subsequent daily energy intake were modified by the length of time to the following meal (18).

We therefore aimed to examine in a sample of 380 healthy participants from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study whether a higher dietary GI, GL, added sugar intake, or a lower dietary fiber intake (or all) between ages 2 and 7 y was related to the development of

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body composition until age 7 y. In addition, we tested for interactions between meal frequency in the toddler years and dietary GI, GL, added sugar intake, or fiber intake for their effect on the development of percentage body fat (%BF) or body mass index (BMI; in kg/m²).

SUBJECTS AND METHODS

Study population

The DONALD Study is an ongoing, open-cohort study conducted by the Research Institute of Child Nutrition (Dortmund, Germany). The study was previously described in detail (19). Briefly, since recruitment began in 1985, detailed information concerning diet, growth, development, and metabolism from infancy to adulthood has been collected for >1200 children. Every year, an average of 40–50 infants are newly recruited and first examined at the age of 3 or 6 mo. From the age of 2 y onward, each child returns once annually until early adulthood. Annual visits include a medical examination, anthropometric measurements, and the completion of a weighed 3-d dietary record. Parents are interviewed, and their child’s anthropometric measurements are obtained by the study nurses upon his or her admission to the study.

The ages of the children who were initially recruited into the DONALD Study were quite variable, and, in some cases, information on the first few years of life was not available. In addition, many of the children have not yet reached the age of 7 y. Therefore, the total number of children for whom anthropometric measurements and dietary data were available at ages 2 and 7 y (at least) was 421. Of these 421, only term (37–42-wk gestation) singletontons with a birth weight <2500 g were included (n = 395). We furthermore excluded 11 children with implausible 3-d dietary records at age 2 y (20) (n = 384). Complete information on maternal overweight, smoking status of the household, and birth variables had to be available for all children (n = 380). Analyses were thus based on ~2200 measurements from 380 children between 2 and 7 y old (4–6 measurements/child).

The parents of each child gave written informed consent to their child’s participation in the study. The study was approved by the Ethics Committee of the University of Bonn.

Anthropometry

At each visit, anthropometric measurements were obtained by trained nurses according to standard procedures (21); the children were dressed only in underwear and were barefoot. The nurses undergo an annual quality-control evaluation in which intraobserver and interobserver agreement is carefully monitored. From the age of 2 y on, the child’s standing height was measured to the nearest 0.1 cm by using a digital stadiometer. Weight was measured to the nearest 0.1 kg by using an electronic scale (Seca 753E; Seca GmbH & Co KG, Hamburg, Germany). From the age of 6 mo on, the child’s skinfold thicknesses were measured to the nearest 0.1 mm on the right side of the body at the biceps, triceps, subscapular, and suprailiac sites; a Holtain caliper (Holtain Ltd, Crymych, United Kingdom) was used.

Sex- and age-independent SD scores (SDS) were calculated by using the German reference curves for BMI (BMI SDS) (22). To remove general deviations in our sample from the reference data, SDS data were internally standardized (mean = 0, SD = 1) before multivariate analyses. The %BF was calculated by using the equations of Deurenberg et al (23). Excess body fat (overfatness) at age 7 y was defined as recently proposed by McCarthy et al—ie, with the use of the 85th percentile of %BF measured by bioimpedance in British children as the cutoff (24). Overweight at age 7 y was defined according to the International Obesity Task Force BMI cutoffs for children, which correspond to an adult BMI of 25 (25). Rapid weight gain in infancy was defined as an increase in weight SDS by >0.67 SDS between birth and age 2 y (26).

Nutritional assessment

Food consumption in the DONALD Study is assessed by using weighed 3-d dietary records as described previously (19). The parents of each child weigh and record all foods and beverages consumed, as well as leftovers, using electronic food scales (±1 g; initially Soehnle Digita 8000; Leifheit SG, Nassau; Germany; now WEDO digi 2000; Werner Dorsch Gmbh, Muenster/Dieburg, Germany) on 3 consecutive days. Recipes for meals prepared at home are recorded. The packaging of commercial food products is kept. Semiquantitative recording (eg, number of spoons or scoops) is allowed if weighing is not possible. At the end of the 3-d recording period, a dietician visits the family and checks the record for completeness and accuracy.

In the present study, mean intakes of energy and nutrients, including fiber, were calculated by using the nutrient database LEBTAB (developed at the Research Institute of Child Nutrition), which is continuously updated to include all recorded food items. LEBTAB is based on the German standard food tables and includes complementary data from other national food tables and data obtained from commercial food products (19).

Dietary variables

Dietary GI was defined as the incremental area under the curve of glucose response after the intake of 50 g carbohydrate from a test food compared with the area under the curve of glucose induced by the same amount of carbohydrate from ingested glucose (27). The GI has been proposed as an indicator of the absolute glucose response induced by a serving of a food (28), and it corresponds to the quantity of carbohydrate-containing foods multiplied by their respective GIs.

For the present analysis, each recorded carbohydrate-containing food was assigned a dietary GI according to a standardized procedure (29). In brief, foods were assigned either a published GI (30), the GI of a close match, or a GI calculated from the GI values of the food’s ingredients by using recipes available from the in-house database. The carbohydrate content of the food was the principal consideration in matching a particular food with a food listed in the tables. Foods containing mainly fat or protein with a carbohydrate content below 5 g/100 g (eg, cold meats) were assigned a GI of 0.

The mean GI and GL of each subject on each day were determined by multiplying the carbohydrate content (in g) of each consumed food by the food’s GI. The sum of these products corresponds to the GL; the mean daily GI is obtained by dividing the GL by the total carbohydrate intake.

The following foods were defined as added sugars: white sugar, brown sugar, raw sugar, corn syrup, corn-syrup solids, high-fructose corn syrup, malt syrup, maple syrup, pancake syrup, fructose sweetener, liquid fructose, honey, molasses, anhydrous dextrose, and crystal dextrose (31). Fruit syrups commonly used as sweeteners in Germany also were considered...
added sugars. Conversely, naturally occurring sugars such as lactose in milk or fructose in fruits were not included.

The dietary fiber content in the LEBTAB database was determined by different enzymatic methods as defined in the respective food table. Since 2003, functional fibers have been specified in LEBTAB but not quantified, and, thus, they were excluded from this analysis to comply with the dietary fiber definition of the Institute of Medicine (32). Cereal fiber was defined as fiber from bread, cereals, pasta, rice, cookies, cakes, pastries, and crackers; fruit fiber was defined as fiber from fruit and fruit products; and vegetable fiber was defined as fiber from vegetables and vegetable products, including potatoes.

A meal was defined as an event at which energy from foods or beverages was consumed. Meals eaten <30 min apart were considered to be one meal. To distinguish toddlers with a consistently lower meal frequency from those with an inconsistent meal frequency or a consistently higher meal frequency, meal patterns at both age 2 y and age 3 or 4 y were used, with the cutoff of <6 meals/d (yes or no) on both occasions.

Full breastfeeding was defined as breast milk only without any supplemental solid foods or liquids, other than tea or water, for ≥4 mo. The age at introduction of solid foods reflected the week in which puréed baby food containing either vegetables (± meat), fruit (± cereals), or milk was fed for the first time. Information on breastfeeding and complementary feeding was obtained from the mother at each visit within the first year of life (ie, at 3, 6, 9, and 12 mo).

**Statistical analysis**

Nutritional intakes at ages 2 and 7 y were compared by paired t test (nutrient intakes) or Wilcoxon’s signed-rank test (intake of food groups). Dietary GI and fiber intake were grouped into age- and sex-specific tertiles to illustrate contributing food groups at ages 2 and 7 y.

Linear mixed-effects regression models were used to construct longitudinal models of %BF and BMI SDS trajectories between ages 2 and 7 y. We used the PROC MIXED procedure in SAS software (version 8.02; SAS Inc, Cary, NC); we used a repeated statement because that accounts for the lack of independence between repeated observations on the same person. A Toeplitz covariance was found to best specify the structure of the within-person error covariance. The age 2 y visit was treated as the baseline visit—ie, time = 0.

GI, GL, added sugar intake, fiber intake, and time (chronological age, age², and age³) were the principal fixed effects. Changes in dietary GI, GL, added sugar intake, or fiber intake between ages 2 and 7 y were calculated by subtracting baseline intake from intake at each year of assessment (visit 1 − visit 0, visit 2 − visit 0, etc). In this way, the respective regression coefficients represent the effects of 1) dietary GI, GL, added sugar intake, or fiber intake at age 2 y on %BF or BMI SDS at age 2 y (cross-sectional estimate); 2) dietary variables at age 2 y on the slope of the change in %BF or BMI SDS from ages 2 to 7 y (prospective estimate); and 3) the slope of the change in the dietary variables on the concurrent change in %BF or BMI SDS for the period from age 2 y to age 7 y (concurrent estimate).

In a further step, nondietary covariates that potentially affect the association between dietary GI, GL, added sugar intake, or fiber intake and body-composition measures were added. These included maternal overweight (BMI ≥ 25), high maternal educational status (≥12 y of schooling), smoking in the household, birth year (1983 was set to 0), birth weight, rapid weight gain between birth and age 2 y, full breastfeeding, and age at introduction of solid foods. For these variables, the interaction with time was also considered, to adjust for any significant effect on the change in body-composition measures over time.

Finally, other nutrition variables (intake of protein or fat and meal frequency) were included. Analogous to dietary GI, GL, added sugar intake, or fiber intake, 3 terms per potential nutritional confounder were considered: 1) intake at age 2 y (baseline); 2) intake at baseline × time; and 3) change in intakes from baseline. All dietary variables were expressed as sex- and age-specific SDS (mean = 0, SD = 1). This approach allowed comparison of all unadjusted models for dietary GI, GL, added sugar intake, and fiber intake (including the concurrent estimate for the period from age 2 y to age 7 y) with the respective energy-adjusted models—ie, SDS were used in models without energy adjustment, and studentized (mean = 0, SD = 1) residuals (33) were used in models with adjustment for energy. Only those variables that significantly modified the effect of the principal dietary variables on %BF or BMI SDS in the basic models, significantly predicted the outcome variable, or improved the fit statistic (ie, Akaike’s Information Criteria) were included in the subsequent multivariate analyses.

Analyses did not indicate any interaction between sex and the associations of dietary GI, GL, added sugar intake, or fiber intake for the development of %BF or BMI SDS. Thus, data from girls and boys were pooled for all analyses. All statistical analyses were carried out by using SAS software (version 8.2; SAS Inc). A P value < 0.05 was considered to indicate statistical significance.

**Power considerations**

The data from 380 children were sufficient to allow detection of cross-sectional differences, at the 0.05 level and with 80% power, of 1.65 in %BF and of 0.31 in BMI SDS at age 7 y between the lowest and the highest tertile of dietary GI, GL, added sugar intake, or fiber intake. The additional information from repeated measurements is likely to have resulted in a higher power in the multilevel models for change.

**RESULTS**

Children included in the present analyses were born between 1983 and 2000 and had a relatively high socioeconomic status (Table 1). The mean BMI SDS values were close to zero at ages 2 and 7 y, which indicated that the BMI of the sample was comparable to that in the German growth reference population. At age 7 y, ≈15% of the children were overweight or overweight according to international cutoffs. Dietary intakes at ages 2 and 7 y are shown in Table 2. Dietary GI, GL, added sugar intake, fiber intake, carbohydrate intake (% of energy), and energy intake increased, whereas intakes of total and saturated fat and protein (% of energy for all) and meal frequency decreased.

Overall, dietary GI, GL, added sugar intake, and fiber intake at age 2 y were not related to %BF. This held true for the cross-sectional analysis (Table 3, first set of values), the prospective analyses (Table 3, second set of values), and the effect of changes in these dietary variables on concurrent %BF development (Table 3, third set of values).
Discussion

To our knowledge, the present study is the first to provide prospective evidence on the relevance of carbohydrate quality to the development of body composition in early childhood. In the present study, dietary GI, GL, added sugar intake, and fiber intake showed no overall association with the development of body composition in childhood, whether cross-sectionally at age 2 y, prospectively until age 7 y, or concurrently. Only those children who consumed <6 meals/d as toddlers experienced a modest benefit to their concurrent %BF development from an increase in fiber intake between ages 2 and 7 y. It has been postulated that dietary GI and GL may be linked to the development of overweight by an increased stimulation of appetite due to reactive hypoglycemia after the ingestion of meals with a high dietary GI (34). Furthermore, the reduced rate of fat oxidation in the late postprandial phase after a high-GI meal may, over the long term, detrimentally affect insulin sensitivity (4). However, in the present study, dietary GI and GL were not related to the development of body composition; this lack of relation considerably extended the findings from most of the cross-sectional studies in schoolchildren (aged 6–17 y), which did not find any independent association between dietary GI and measures of body composition (35–38). In contrast, Nielsen et al (39) reported that a higher dietary GI was related to a higher sum of skinfold thicknesses; however, this association was seen only in 16-y-old Danish boys—not in 10-y-old boys or 10–16-y-old girls. The absence of the proposed association in the present

Table 2  Nutritional intake at ages 2 and 7 y in a sample of 380 healthy children from the DOrtMund Nutrition and Anthropometric Longitudinally Designed (DONALD) Study

<table>
<thead>
<tr>
<th>Nutritional at</th>
<th>Age 2 y</th>
<th>Age 7 y</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI (g/d)</td>
<td>51.7 ± 3.5</td>
<td>55.8 ± 3.0</td>
</tr>
<tr>
<td>GL (g/d)</td>
<td>62.8 ± 14.6</td>
<td>112.8 ± 24.4</td>
</tr>
<tr>
<td>Added sugar (% of energy)</td>
<td>9.5 ± 5.1</td>
<td>14.2 ± 5.4</td>
</tr>
<tr>
<td>Fiber (g/d)</td>
<td>10.3 ± 3.4</td>
<td>16.2 ± 4.4</td>
</tr>
<tr>
<td>Cereal fiber (g/d)</td>
<td>4.4 ± 2.2</td>
<td>8.0 ± 3.2</td>
</tr>
<tr>
<td>Fruit fiber (g/d)</td>
<td>2.8 ± 1.7</td>
<td>3.3 ± 1.9</td>
</tr>
<tr>
<td>Vegetable fiber (g/d)</td>
<td>2.4 ± 1.4</td>
<td>3.0 ± 1.7</td>
</tr>
<tr>
<td>Carbohydrate (% of energy)</td>
<td>49.3 ± 6.7</td>
<td>52.0 ± 5.0</td>
</tr>
<tr>
<td>Fat (% of energy)</td>
<td>37.2 ± 5.9</td>
<td>35.4 ± 4.6</td>
</tr>
<tr>
<td>Saturated fatty acids (% of energy)</td>
<td>17.3 ± 3.2</td>
<td>15.8 ± 2.6</td>
</tr>
<tr>
<td>Protein (% of energy)</td>
<td>13.5 ± 2.1</td>
<td>12.6 ± 1.9</td>
</tr>
<tr>
<td>Total energy (kcal/d)</td>
<td>983 ± 159</td>
<td>1540 ± 280</td>
</tr>
<tr>
<td>Meal frequency &lt;6 meals/d [%]</td>
<td>152 (40.0)</td>
<td>234 (61.6)</td>
</tr>
<tr>
<td>≥ 6 meals/d [%]</td>
<td>228 (60.0)</td>
<td>146 (38.4)</td>
</tr>
</tbody>
</table>

1 GI, glycemic index; GL, glycemic load. All nutritional variables differed significantly between ages 2 and 7 y, P < 0.0001 (paired t test).
2 Dietary GI was calculated by using the scale of glucose = 100.
3 x ± SD (all such values).
study could be due to the fact that a meal with a high dietary GI exerts its detrimental metabolic effects in the late postprandial phase (34). We speculate that toddlers commonly consume their next meal before reactive hypoglycemia has had a chance to occur.

In the present study, we did not observe any independent association of added sugar intake with the development of body composition. In a recent cross-sectional study, Davis et al (38) also reported no association between added sugar intake and adiposity measures among 10-17-y-old Latino youths. However, in their analysis, total fat mass was related to total sugar intake, a variable not available in the present analysis. It is interesting that our analyses indicated potentially protective influences of added sugar intakes on BMI SDS before adjustment for dietary covariates. However, in our cohort of young children, consumption of a higher percentage of energy from added sugar was associated with ingestion of a lower percentage of energy from dietary protein (data not shown). Thus, the associations of added sugar intake with BMI SDS probably reflected a protective effect of lower protein intake in childhood, especially because this effect was no longer evident after adjustment for protein intake. A previous analysis by our group (40) showed not only that higher protein intakes in early childhood are associated with higher BMI SDS levels at age 7 y but also that these adverse associations were largely attributable to protein from dairy sources. Similarly, added sugars from different food sources have been reported to be differentially associated with the quality of the diets of children and adolescents (41). We cannot, therefore, exclude the possibility that total sugar intake or added sugar from specific food groups (eg, sugar-sweetened beverages or sweets) may also adversely affect the development of body composition in early childhood.

Fiber intake was not related to weight change in the only prospective study in children and adolescents that is available to date (42). The findings of the present analysis suggest that the length of time between meals may play a role in the association between dietary fiber intake and body composition; only children with consistently low meal frequency as toddlers (ie, those with a length of time between meals) appeared to benefit from an increase in fiber intake throughout childhood. Because this interaction with meal frequency was not seen for dietary GI, we believe that the effects of dietary fiber that are relevant in the subgroup of children with a lower meal frequency did not result from an influence on postprandial blood glucose concentrations. It has recently been suggested, however, that insoluble cereal fiber may reduce appetite and short-term food intake via a prolonged secretion of glucagon-like peptide in the distal small intestine (43). The findings of the present study could be explained by such satiating effects, because we observed an effect of the interaction between meal frequency and increase in fiber intake for concurrent %BF development only for cereal fiber intake. Nonetheless, it should be noted that the overall observed

### Table 3

<table>
<thead>
<tr>
<th>Nutritional intake at age 2 y in relation to %BF at age 2 y</th>
<th>Change in %BF from age 2 y to 7 y</th>
<th>Increase in intake in relation to concurrent change in %BF at age 2 y to 7 y</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glycemic index</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted for sex only</td>
<td>$-0.024 (0.143)$</td>
<td>0.9</td>
</tr>
<tr>
<td>Adjusted for nondietary variables</td>
<td>$-0.128 (0.134)$</td>
<td>0.3</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>$-0.058 (0.146)$</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Glycemic load (g/d)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted for sex only</td>
<td>$-0.168 (0.143)$</td>
<td>0.2</td>
</tr>
<tr>
<td>Adjusted for nondietary variables</td>
<td>$-0.277 (0.134)$</td>
<td>0.04</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>$-0.079 (0.197)$</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Added sugar intake (% energy)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted for sex only</td>
<td>$-0.163 (0.143)$</td>
<td>0.3</td>
</tr>
<tr>
<td>Adjusted for nondietary variables</td>
<td>$-0.161 (0.134)$</td>
<td>0.2</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>$-0.252 (0.170)$</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Fiber intake (g/d)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted for sex only</td>
<td>$-0.100 (0.143)$</td>
<td>0.5</td>
</tr>
<tr>
<td>Adjusted for nondietary variables</td>
<td>$-0.174 (0.133)$</td>
<td>0.2</td>
</tr>
<tr>
<td>Fully adjusted model</td>
<td>$-0.157 (0.148)$</td>
<td>0.3</td>
</tr>
</tbody>
</table>

1. AIC, Akaike’s Information Criteria. Data are from linear mixed regression models. Models contain a repeated statement with a Toeplitz covariance.
2. Intakes are expressed as SDs. 1 SD in glycemic index is equivalent to ≈3.0–3.5, 1 SD in glycemic load is equivalent to ≈15–24 g/d, 1 SD in added sugar is equivalent to ≈5.1–5.4% of energy, and 1 SD in fiber is equivalent to ≈3.4–4.4 g/d.
3. Adjusted for age, age2, age3, sex, maternal overweight, year of birth, birth weight (g), and rapid weight gain between birth and age 2 y (each separately and in interaction with time).
4. Adjusted for age, age2, age3, sex, maternal overweight, year of birth, birth weight (g), and rapid weight gain between birth and age 2 y (each separately and in interaction with time).
benefit for children with a lower meal frequency as toddlers was modest and likely to be of limited clinical relevance.

It could be argued that the fiber intakes in the present study were too low to affect body composition. Recent analyses of data from the DONALD Study showed that fiber intake recommendations were not met by children, including toddlers aged 2 y (44). However, in early childhood, the optimal intake of dietary fiber is still subject to debate, because potentially adverse effects of a high dietary fiber intake on growth and mineral absorption have to be balanced with the presumed benefits. Evidence from early childhood for both benefits and adverse effects is scarce, and dietary recommendations for fiber intake are at present largely extrapolated from evidence in adulthood (45). Similarly, the dietary GI or GL in the present study may have been too low to affect satiety, blood glucose concentrations, or substrate utilization. However, the dietary GI at age 7 y was comparable to that in other studies of school-aged children (29, 36, 39).

Finally, the children in the present study may have been too healthy to respond to any detrimental effect potentially exerted by a lower quality of dietary carbohydrate. Intervention studies have shown that a low dietary GL may represent a promising weight-loss diet, particularly among persons with high insulin secretion (46, 47). We did not have data on insulin secretion or insulin sensitivity, and our sample included only a few overweight children, who may not yet be insensitive to insulin.

A number of other limitations should be mentioned. First, for ≈34% of the carbohydrate-containing foods, we had to calculate GI values from the foods’ ingredients. Whereas this procedure is controversial (48), other reports suggest that the GI of a whole diet or mixed meal can be accurately estimated from the GI values of the constituent foods (49, 50). Furthermore, because GI values are currently available for only ≈1800 carbohydrate-containing foods, GI calculation appears to be the only feasible approach for epidemiologic studies, such as ours, that have detailed data on the carbohydrate-containing foods. Second, we were not able to adjust for physical activity, and a higher fiber intake could reflect a healthier lifestyle. However, to partially adjust for potential confounders such as caloric intake, we were able to adjust for smoking, and our sample included only children with normal BMI SDS by age 7 y, which is an indication of normal body composition.

The third, %BF was estimated from skinfold-thickness measurements, which, due to the variability of the method, are not as accurate as measures of body composition such as dual-energy X-ray absorptiometry (51).

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in interaction with time) and for intakes of energy, protein, glycemic index, and added sugar at age 2 y, intake at age 2 y and in interaction with time).

from age 2 y to 7 y.

REFERENCES

AEB and NK-D: supervised the study; and all authors: interpreted the project, performed the data analyses, and drafted the manuscript; ALBG, collecting and processing the nutritional data.

Young children eating meals 6 times/d at both age 2 y and age 3 or 4 y.

Table 5

| Fiber at age 2 y in relation to | Increase in fiber intake in relation to concurrent change in %BF | AIC
|---|---|---|
| %BF at age 2 y | Change in %BF from age 2 y to 7 y | P | P | AIC
| Children with a lower meal frequency (n = 133) | | | | |
| Adjusted for sex only | 0.032 (0.244) | 0.9 | -0.081 (0.065) | 0.2 | -0.226 (0.090) | 0.01 | 3407 |
| Fully adjusted model | -0.039 (0.256) | 0.9 | -0.008 (0.071) | 0.9 | -0.258 (0.091) | 0.005 | 3374 |
| Children with a higher meal frequency (n = 247) | | | | |
| Adjusted for sex only | -0.202 (0.175) | 0.3 | 0.033 (0.046) | 0.5 | 0.046 (0.067) | 0.5 | 6301 |
| Fully adjusted model | -0.256 (0.178) | 0.2 | 0.081 (0.047) | 0.08 | 0.074 (0.070) | 0.3 | 6251 |

1 AIC, Akaike’s Information Criteria. Data are from linear mixed regression models. Fiber intakes are expressed as SDs. 1 SD in fiber intake is equivalent to 3.4–4.4 g/d. Models contain a repeated statement with a Toeplitz covariance. Interactions between concurrent percentage body fat change and change in fiber intake: P = 0.02 in model adjusted for sex only, P = 0.01 in fully adjusted model.

2 Smaller AIC values are better.

3 Lower meal frequency: <6 meals/d at both age 2 y and age 3 or 4 y.

4 Adjusted for age, age 2, age 3, sex, maternal overweight, year of birth, birth weight (g), and rapid weight gain between birth and age 2 y (each by itself and in interaction with time).

5 Adjusted for age, age 2, age 3, sex, maternal overweight, year of birth, birth weight (g), and rapid weight gain between birth and age 2 y (each by itself and in interaction with time) and for intakes of energy, protein, glycemic index, and added sugar at age 2 y, intake at age 2 y x time, and difference in intake from age 2 y to 7 y.

Relation of dietary fiber intake during childhood to development of percentage body fat stratified by meal frequency.

The present study has considerable strengths, including its prospective nature, repeated detailed measurement of both anthropometric and dietary data, and the ability to adjust for numerous major potential confounders. The repeated-measures regression analysis allowed us simultaneously to compare cross-sectional and longitudinal aspects of our prospective data and also to account for within-person correlations. In particular, the “change-on-change” analysis has been proposed to possess features of a quasi-experimental design (53), in which some participants are assigned to a change in dietary GI, GL, added sugar intake, or fiber intake, and other participants are not so assigned.

On the whole, the present study does not support the common view that the quality of carbohydrate may be implicated in the current obesity epidemic in childhood. At least among healthy young children eating ≥6 times/d, carbohydrate quality does not appear to be relevant to their body-composition development between ages 2 and 7 y, whether cross-sectionally, prospectively, or concurrently. For toddlers eating less frequently, an increase in their intake of fiber may offer a modest benefit for their concurrent %BF development.

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