Increased consumption of refined carbohydrates and the epidemic of type 2 diabetes in the United States: an ecologic assessment 1–3

Lee S Gross, Li Li, Earl S Ford, and Simin Liu

ABSTRACT

Background: Type 2 diabetes is an epidemic that is affecting an ever-increasing proportion of the US population. Although consumption of refined carbohydrates has increased and is thought to be related to the increased risk of type 2 diabetes, the ecologic effect of changes in the quality of carbohydrates in the food supply on the risk of type 2 diabetes remains to be quantified.

Objective: The objective was to examine the correlation between consumption of refined carbohydrates and the prevalence of type 2 diabetes in the United States.

Methods: In this ecologic correlation study, the per capita nutrient consumption in the United States between 1909 and 1997 obtained from the US Department of Agriculture was compared with the prevalence of type 2 diabetes obtained from the Centers for Disease Control and Prevention.

Results: In a univariate analysis, a significant correlation with diabetes prevalence was observed for dietary fat (r = 0.84, P < 0.001), carbohydrate (r = 0.55, P < 0.001), protein (r = 0.71, P < 0.001), fiber (r = 0.16, P = 0.03), corn syrup (r = 0.83, P < 0.001), and total energy (r = 0.75, P < 0.001) intakes. In a multivariate nutrient-density model, in which total energy intake was accounted for, corn syrup was positively associated with the prevalence of type 2 diabetes (β = 0.0132, P = 0.038). Fiber (β = −13.86, P < 0.01) was negatively associated with the prevalence of type 2 diabetes. In contrast, protein (P = 0.084) and fat (P = 0.79) were not associated with the prevalence of type 2 diabetes when total energy was controlled for.


KEY WORDS Type 2 diabetes, obesity, dietary fiber, refined carbohydrate, dietary carbohydrate, glycemic index

INTRODUCTION

Obesity and type 2 diabetes are occurring at epidemic rates in the United States (1–3). From 1935 to 1996, the prevalence of diagnosed type 2 diabetes climbed nearly 765% (4). Currently, > 16 million Americans have type 2 diabetes, one-third of whom do not even know that they have the disease (5). Recent data suggest that 47 million Americans have the metabolic syndrome—an insulin resistance syndrome that is associated with an increased risk of type 2 diabetes (6). The prevalence of adult obesity increased a staggering 57% in the brief period between 1991 and 1999, and currently > 60% of US adults are overweight (3, 7). These increases cannot be explained by the aging of the population alone, because similar increases are also being seen in US children (8).

The cause of type 2 diabetes is multifactorial. Factors such as changes in exercise patterns and the ethnic composition of the US population are likely contributors to the rising trends in diabetes, but there have been many debates in the scientific literature about the effects of specific dietary macronutrients on the risk of obesity and type 2 diabetes (9–12). Recent data suggest that a high intake of refined carbohydrates may increase the risk of insulin resistance (13–16). Although an increase in the intake of refined carbohydrates in the form of processed grains, soft drinks, sweeteners, and refined flours in the US food supply has been reported, scant quantitative data exist to determine whether such changes in dietary composition are related to the current epidemic of obesity and type 2 diabetes in the United States. To address this issue, we examined almost one century of dietary data and the history behind changes in the US diet. We conducted a multivariate analysis of the correlation between changes in the prevalence of type 2 diabetes and changes in dietary patterns in the United States.

METHODS

We obtained estimates of the prevalence of type 2 diabetes in the United States from the National Health Interview Surveys maintained by the Centers for Disease Control and Prevention’s Diabetes Surveillance System (4, 17). Such data are available for 1935 and then annually beginning in 1957 and are based on self-reports of having received a diagnosis of type 2 diabetes. In 1997, adoption of the type 2 diabetes diagnostic criteria of the World Health Organization effectively increased the prevalence of type 2 diabetes in the United States after that year (18). We
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The prevalence of obesity was based on the measured height and weight of a random sample of the civilian noninstitutionalized population aged ≥20 y, and is reported as a percentage of the US population with a body mass index (BMI; kg/m²) of ≥30. The data came from the National Health Examination Survey (NHES 1960–1962); the first, second, and third National Health and Nutrition Examination Surveys (NHANES I, 1971–1974; NHANES II, 1976–1980; NHANES III, 1988–1994); and NHANES 1999.

Unless stated otherwise, the nutrient content of the US food supply and other nutrition data were obtained from the National Nutrient Data Bank, which is maintained by the Center for Nutrition Policy and Promotion and the Economic Research Service of the US Department of Agriculture (20). Nutrient data are based on food disappearance and were calculated with the use of food availability data from the Economic Research Service and on the basis of the nutrient content of the edible portion of the available food supply as calculated by the Nutrient Data Laboratory of the Agricultural Research Service. These food-composition data are the numerical foundation of essentially all public and private work in the field of human nutrition (20).

Regression analysis was performed to examine the correlation between macronutrient consumption and disease rates. A multivariate nutrient-density model was used to control for total energy intake (21). In particular, corn syrup was selected to represent refined carbohydrates in the model, because it is a highly refined substance that is consumed in vast quantities in the United States in the form of soft drinks, commercial baked goods, ready-to-eat breakfast cereals, and many other commercially processed food products. Similarly, dietary fiber was selected because it generally is removed during the refining process. All P values are two sided. The statistical analysis was performed with the use of EPI-INFO (2002; Centers for Disease Control and Prevention, Atlanta).

RESULTS

Dietary carbohydrate steadily decreased from 500 g/d in 1909 to 374 g/d in 1963, largely because of a decrease in the consumption of whole grains. Simultaneously, dietary fiber decreased at a greater rate—by nearly 40%. Since 1963, the consumption of carbohydrates steadily increased back to 500 g/d; however, fiber consumption did not increase proportionately. This finding reflects an increased consumption of refined carbohydrates over this time period (Figure 1). From 1963 to 1997, the consumption of total fat increased nearly 30%, protein consumption increased 8%, and total energy consumption increased 9%.

In a univariate analysis of the available data for the period between 1909 and 1997, a significant correlation with the prevalence of type 2 diabetes was observed for intakes of dietary fat ($r = 0.84, P < 0.001$), carbohydrate ($r = 0.55, P < 0.001$), protein ($r = 0.71, P < 0.001$), fiber ($r = 0.16, P = 0.027$), corn syrup ($r = 0.83, P < 0.001$), and total energy ($r = 0.75, P < 0.001$).

In a multivariate nutrient-density model (Table 1)—in which total energy, corn syrup, fiber, fat, and protein intakes were simultaneously included—corn syrup was positively associated with the prevalence of type 2 diabetes ($β = 0.0132, P = 0.038$), whereas dietary fiber ($β = -13.86, P < 0.01$) was negatively associated with the prevalence of type 2 diabetes. In contrast, the percentages of energy from protein ($P = 0.083$) and fat ($P = 0.79$) were not associated with the prevalence of type 2 diabetes after adjustment for total energy intake and other dietary variables in the multivariate nutrient-density model.

United 1980, the total energy intake remained relatively constant. Between 1980 and 1997, however, total energy intake increased by >500 kcal/d. This increase was due primarily to increases in dietary carbohydrate. Specifically, 428 kcal (nearly 80% of the increase in total energy) came from carbohydrates, 64 kcal (12% of the increase in total energy) came from protein, and only 45 kcal (8% of the increase in total energy) came from fat. This represents a relative increase in consumption of dietary carbohydrates from 48% to 54% of total energy intake over a 20-y period and a relative decrease in dietary fat from 41% to 37% of total energy intake. During the same period, the prevalence of type 2 diabetes increased by 47% and the prevalence of obesity increased by 80%, indicating a significant positive correlation between the percentage of energy from refined carbohydrates and the prevalence of type 2 diabetes and obesity.

The total per capita use of caloric sweeteners increased by 86% between 1909 and 1997, and the type of sweeteners used also changed dramatically. Corn syrup sweeteners, which were almost nonexistent at the beginning of the century, now comprise

![Figure 1. Change in total carbohydrate consumption (○) and the percentage of carbohydrate from fiber (vertical bars) in the United States between 1909 and 1997 (17).](http://example.com/fig1.png)

**TABLE 1**

Multivariate nutrient-density model for examining the associations between trends in nutrients and the prevalence of type 2 diabetes in the United States

<table>
<thead>
<tr>
<th>Nutrient contribution</th>
<th>β Coefficient</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dietary fiber (% of energy)</td>
<td>-13.86</td>
<td>0.0083</td>
</tr>
<tr>
<td>Corn syrup (% of energy)</td>
<td>0.0132</td>
<td>0.038</td>
</tr>
<tr>
<td>Protein (% of energy)</td>
<td>-3.58</td>
<td>0.084</td>
</tr>
<tr>
<td>Fat (% of energy)</td>
<td>0.00196</td>
<td>0.79</td>
</tr>
<tr>
<td>Total energy (kcal)</td>
<td>0.00011</td>
<td>0.28</td>
</tr>
</tbody>
</table>

1 A positive β coefficient indicates an increased risk of type 2 diabetes, whereas a negative coefficient indicates a decreased risk of type 2 diabetes. All values are adjusted for each other. Energy value used for fiber = 4 kcal/g.
> 20% of the total daily carbohydrate intake and 10% of the daily total energy intake, which represents an increase of > 2100%. These sweeteners have surpassed sucrose as the leading sweetener in the US food industry and account for much of the rebound increase in carbohydrate consumption after the mid-1960s, largely replacing the losses due to whole grains (Figure 2). There was a significant correlation between the percentage of carbohydrate from corn syrup and the prevalence of type 2 diabetes ($r = 0.85, P < 0.001$; Figure 3).

The multivariate nutrient-density model was modified to determine the "toxicity" of changing carbohydrate quality. This model included total carbohydrate, the percentage of carbohydrates from corn syrup, and the percentage of carbohydrates from fiber. In this model, corn syrup and fiber—potential indicators of carbohydrate quality—accounted for 18% of the variability in the prevalence of diabetes when the intake of total carbohydrate was controlled for.

**DISCUSSION**

In this ecologic analysis, in which national data from 1909 to 1997 were used, we found a strong association between an increased consumption of refined carbohydrates in the form of corn syrup, a decreased consumption of dietary fiber, and an increasing trend in the prevalence of type 2 diabetes in the United States during the 20th century. Furthermore, our data are consistent in that obesity and the prevalence of diabetes increased proportionately to the increase in consumption of refined carbohydrates in the United States (Figures 4–6).

Our data also indicate that modern carbohydrates are considerably different from those consumed before the beginning of the 20th century and that the US food supply has become reliant on highly refined carbohydrates as significant sources of energy. The refining process has changed the composition and thus the quality of carbohydrates (22). For example, processing whole grains into white flour actually increases the caloric density by > 10%, reduces the amount of dietary fiber by 80%, and reduces the amount of dietary protein by almost 30% (23). Refining removes many of the main ingredients, leaving a dietary substance that is nearly pure starchy carbohydrate with fewer nutrients (24).

Corn refining in the United States began around the time of the Civil War with the development of cornstarch (25). In 1866, it was discovered that cornstarch could be converted to glucose, and by 1882 the corn industry was manufacturing "refined corn sugar." The remainder of the corn plant (fiber, germ, and protein) that was removed in the refining process was sold for animal feed or for the conversion to corn oil. Corn syrup technology advanced significantly with the introduction of enzyme-hydrolyzed products. In 1921, crystalline dextrose hydrate was introduced. The purification and crystallization of glucose meant that, for the first time, corn-based sweeteners could compete in some markets that had been the sole domain of the sugar industry. In the mid-1950s, the technology for commercially preparing low-conversion products such as maltodextrin syrup was developed. The next
Glucose to fructose. The commercial production of high-fructose development involved the enzyme-catalyzed isomerization of grains in the form of ready-to-eat cereals (14, 17). The United States between 1966 and 1997 with increasing consumption of refined grains in the form of ready-to-eat cereals (14, 17).

although dietary fructose and glucose were significantly associated with increased risk (72).

Our analysis confirmed that during the past century, especially the past 20 y, the American diet has undergone a dramatic change. Furthermore, our data indicate that, during the same period, type 2 diabetes has reached epidemic proportions, exerting a substantial health burden on society. These population-level data are consistent with findings from metabolic and prospective studies of individual persons, which suggest that the intake of refined carbohydrates increases the risk of obesity, glucose intolerance, dyslipidemia, and type 2 diabetes. The risk of type 2 diabetes may be reduced by replacing refined carbohydrates with low-GI carbohydrate sources and whole-grain, high-fiber products. Further prospective randomized trials are necessary to determine the absolute effect of such an intervention.

LSG was responsible for the concept and design of the study, acquisition of data, analysis and interpretation of data, drafting of the manuscript, and critical review of the manuscript for important intellectual content. LL and SL were responsible for the concept and design of the study, the analysis and interpretation of data, the drafting of the manuscript, the critical review of the manuscript for important intellectual content, and statistical expertise. None of the authors had any personal or financial interests in this manuscript.

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