High-fructose corn syrup: is this what’s for dinner?1–3

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ABSTRACT

Background: Research on trends in consumption of added sugar and high-fructose corn syrup (HFCS) in the United States has largely focused on calorically sweetened beverages and ignored other sources.

Objective: We aimed to examine US consumption of added sugar and HFCS to determine long-term trends in availability and intake from beverages and foods.


Results: Availability and consumption of HFCS and added sugar increased over time until a slight decline between 2000 and 2004. By 2004, HFCS provided roughly 8% of total energy intake compared with total added sugar of 377 kcal/person · d−1, accounting for 17% of total energy intake. Although food and beverage trends were similar, soft drinks and fruit drinks provided the most HFCS (158 kcal/person · d−1 of energy intake). Among consumers, sweetened tea and desserts also represented major contributors of calories from added sugar (>100 kcal/person · d−1).

Conclusion: Although increased intake of calories from HFCS is important to examine, the health effect of overall trends in added caloric sweeteners should not be overlooked.

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INTRODUCTION

Over the past decade, extensive research has focused on understanding both the trends and the consequences of the large increases in caloric sweeteners consumed in the United States. Much of the research has focused on the beverage sector, where several excellent meta-analyses have examined the effects of caloricily sweetened beverage drink intake on energy intake, weight gain, and diabetes (1–3). Extensive research has documented both the large amounts of added caloric sweeteners in the diet and the large increases in the consumption of these sweeteners over the past 2 decades (4–9). High-fructose corn syrup (HFCS) has been used increasingly as a replacement for other caloric sweeteners, first in beverages, and more recently, as a replacement for sugar in thousands of other processed and packaged foods (10). A causal link between increased consumption of HFCS and obesity has been hypothesized (10), and although animal research (11–14) and a small number of human studies (15, 16) support this hypothesis, Bray et al note (10) that extensive human research on this topic is limited and deserves further attention.

HFCS is interesting for many reasons. At equal caloric value, HFCS is both sweeter and less expensive than other added sweeteners. Thus, food and beverage manufacturers were able to increase the sweetness of their products for a fraction of the price. The overall result has been an increase in the intensity of the sweetness of soft drinks and other caloric beverages (10, 17). There is some potential for disagreement on this point, but only indirect evidence exists (18).

In part, the shift from using sucrose to HFCS was encouraged by extensive government subsidies of corn farmers, with a majority of US farm policies focused on promoting increased production of inexpensive corn. One study showed that as a result of such subsidies, the consumer price of corn (and its byproducts) remained ≈25–30% below cost (of production) between 1997 and 2005 (19). For beverage manufacturers, in particular, lower sweetener costs allowed increased serving sizes (which would be only marginally more expensive for the consumer), thus freeing money for marketing campaigns (20). Although far less studied, similar trends have likely occurred in other food sectors. However, HFCS should not be studied independently of the context of trends in total caloric sweetener consumption. With rising corn prices and a farm bill proposing to remove some of the corn subsidies, it is possible that HFCS prices will begin to rise considerably. Were this to occur, it may result in the substitution of another caloric sweetener for HFCS, resulting in continued consumption of sweetened, refined carbohydrates in the United States.

This study focuses on updating our understanding of the consumption of both HFCS and other added caloric sweeteners. Essentially, these added sugars are found in thousands of food items consumed in the United States and globally (21, 22). Unlike prior studies, the present study expands the efforts of previous researchers to estimate added sugars and HFCS consumption.

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METHODS

Availability of HFCS

Given the absence of direct measures of HFCS consumption, food disappearance data provide the best indirect estimate of HFCS availability in the US. We used data from the US Department of Agriculture’s (USDA’s) Economic Research Service Food Availability Databases (23) to examine the availability of total sugars and HFCS. Measures of total caloric sweetener and HFCS availability were taken directly from this data. Using measures of total HFCS availability in pounds per person per day, we further calculated the proportion of HFCS that is HFCS-42 versus HFCS-55. These 2 formulations of HFCS refer to the percentage of the sweetener that is fructose, ie, HFCS-42 has 42% fructose and 58% glucose. HFCS-55 has sweetness equivalent to sucrose and is used in many carbonated soft drinks, particularly in the United States. HFCS-42 is somewhat less sweet and is used in many fruit-flavored noncarbonated beverages, baked goods, and other products. All results account for production and import and are adjusted for loss, waste, and spoilage. Data were available from 1970 through 2004 (23).

Foods containing HFCS

Comprehensive information on foods and beverages containing HFCS is not readily available and must be pieced together from various sources. It is clear that HFCS accounts for almost all added caloric sweeteners used by manufacturers of soft drinks and fruit drinks as well as other specialty calorically sweetened beverages (24, 25). In addition, HFCS can be found in numerous processed foods, including canned foods (eg, soups, fruits), cereals and baked goods, desserts, sweetened and flavored dairy products (eg, yogurt, condiments, and jellies), candies, and many fast food items. Most of the information on availability comes from lists compiled by individuals who have examined ingredients of foods in their homes or from organizations concerned with HFCS-related food allergies (26–28). Direct measurements of the HFCS composition of foods are not available from manufacturers or publicly available food-composition tables. For the purposes of this article, foods that had either added sugar or fructose were considered to potentially contain HFCS.

Estimating HFCS and added sugar in foods

We obtained direct estimates of added sugar by using the USDA food-composition table and its recipe and servings files. The recipe and servings files provide a direct measure of added sugar in each food. Because direct estimates of HFCS are not available, and because the existing literature on this topic is scarce, we elected to estimate the HFCS content in foods and beverages by using 2 different techniques referred to as the NDS and Glinsmann methods. These are discussed in detail below.

NDS method

This method uses measured total fructose and added sugar from the University of Minnesota’s Nutrition Coordinating Center (NCC) Nutrient Database System (NDS) sugars file and measures of added sugar from the USDA food-composition table. The USDA Nutrient Data Laboratory is the primary source of nutrient values and nutrient composition within the NDS. However, these values are supplemented by food manufacturers’ information and data that are available in the scientific literature (29). Using data from NDS was the only way we could obtain direct measures of fructose for sample foods. For all foods and beverages, except soda and fruit drinks (for which HFCS was assumed to be 100% of added sugar), we used a 3-step process to estimate HFCS. The steps were as follows:

1) Calculation of the proportion of added sugar that is fructose

Using added sugar and fructose values provided for 988 foods in the NDS sugars database, we determined the proportion of added sugar that is fructose \( P_f \) by dividing fructose (g/100 g food) by added sugar (g/100 g food). This calculation was carried out for each food code individually.

2) Estimation of the amount of added sugar that is HFCS

We found direct matches between NDS and USDA food codes for roughly 50% of the data. For these foods, the \( P_f \) was multiplied by the amount of added sugar in each food as reported by the USDA. This resulted in an estimate of the gram amount of HFCS per food code. This value was then multiplied by the amount of added sugar per food reported for a total estimate of HFCS by food for each respondent. For example, “fruit flavored juice drinks” had 13.575 g fructose/100 g drink and 37.078 g total added sugar/100 g drink. The estimated proportion of added sugar that was fructose \( P_f = (13.575/37.078) \times 100 = 36.6\% \) was multiplied by the amount of “fruit flavored juice drinks” reported consumed by each respondent.

For food codes where no direct match between NDS and USDA was possible, we multiplied the mean proportion of fructose \((P_f)\) assigned to each food codes’ larger food group (described in detail below) by the amount of added sugar in each food as reported by the USDA.

3) Generation of measure of HFCS by food group

HFCS consumption was calculated for each food and summed across food groups. Data are presented by food group across time.

Glinsmann method

In 1986, a task force for the Food and Drug Administration produced estimates of intake of natural and added sugars, including HFCS, sucrose, and other corn sweeteners (30). Using data on HFCS and added sugar availability (by food group), Glinsmann et al created category-wide estimates of the proportion of added sweetener that is HFCS. For example, of the 1684.24 million kg (3713.12 million lbs) of added sweetener available to the bakery and cereal industry in 1984, 278.00 million kg (612.87 million lbs, or 16.5%) was HFCS. Thus, a factor of 0.165 was multiplied by the amount of added sugar in the “grains” food group to obtain an estimate of HFCS. As with the previous method, 100% of added sugar in soda and fruit drinks was assumed to be HFCS. Within food groups, we generated estimates of HFCS by applying these factors to the amount of added sugar reported in the USDA food-composition table and summed intake by food group.

Although we present results from both methods for comparison, the results reported here are based on the Glinsmann method.
of estimation. This method was selected for several reasons. First, unlike the NDS method, the proportions estimated by Glinsmann et al had been successfully implemented in at least one previous study of HFCS consumption (10). Secondly, NCC data were not intended, nor established, for application to the USDA survey data, and used a different set of food identifiers. Additionally, the NCC data use the NDB foods, which were divided differently from the USDA survey foods, which further complicated the matching process. This meant that matching with the USDA survey data was poor, resulting in a 50% match rate. For the remaining 50% of foods, food group means were applied. This may have resulted in a “washing out” of our HFCS estimates. Furthermore, the total fructose value provided by NDS required assumptions (not based on scientific literature) about the proportion of added sugar that is HFCS versus some other form of fructose sweetener.

**Estimated timing of HFCS use in the food supply**

Precise information on the introduction of HFCS as an added sweetener into the food supply was not available. Various sources cited the early 1980s as the years when Coca-Cola and Pepsi introduced the reformulation of their beverages to include HFCS (20, 31), at which point HFCS was the sole added sweetener in these beverages. For nonbeverage categories, there is evidence of HFCS use started in the late 1980s. However, information that would allow for accurate estimates of the amount used was not available until the last period, 1999–2004. For these years, adequate evidence shows that HFCS was used much more widely in the general food supply. Thus, we applied the mean proportion of fructose ($P_f$) for each food group’s added sugar for this period only.

**Food group creation**

Foods were initially grouped by using the University of North Carolina (UNC) food-grouping system (32), which places foods and beverages into nutrient-based subgroups on the basis of their fat and fiber contents. However, these food groups varied widely with respect to added sugar values. Because these groups would ultimately be used to provide estimates of the fructose proportion for foods that did not have a direct match between NDS and USDA, the original food groups were modified. Fat and fiber distinctions were removed, and foods were regrouped according to added sugar. For example, the low, medium, and high-fat dairy UNC food groups were separated into dairy no sugar added, dairy low sugar added (below the mean for grams of added sugar), and dairy high sugar added (at or above the mean for grams of added sugar). Finally, the beverage groups, which were combined with all other food groups in the original UNC food grouping system (ie, low-fat milk was grouped with low-fat dairy products, such as cottage cheese), were redefined and categorized in accordance with the Beverage Guidance Panel (33). For the examination of trends, the sugar groups were combined (ie, no sugar, low sugar, and high sugar desserts presented as desserts).

**Consumption data**

We used data from the Nationwide Food Consumption Survey [NFCS 1965–1966 ($n = 13,549$) and 1977–1978 ($n = 29,553$)], the Continuing Survey of Food Intake in Individuals [CSFII 1989–1991 ($n = 14,689$)] and the National Health and Nutrition Examination Survey [NHANES 1999–2004 ($n = 25,482$)] to examine trends in estimated HFCS consumption. Dietary intake data from NCFS 1965–1966 were collected by using a single, interviewer-administered 24-h recall. Data from NCFS 1977–1978 and CSFII 1989–1991 were collected over 3 consecutive days by use of a single interviewer-administered 24-h recall followed by a 2-d self-administered diet record. Information on all foods and beverages consumed, regardless of location, was recorded. We used only the first day’s 24-h recall to maintain consistency in data collection methods between these study years (ie, 1965–1991).

Beginning with NHANES 1999–2000, a validated (34), semi-automated (fully automated in 2002), multiple-pass method of an interviewer-administered 24-h dietary collection was introduced. This 5-step computer-assisted dietary recall instrument has been cited as an improvement over previous methods for collecting dietary recall information because it includes multiple probes for potentially forgotten foods and beverages and asks about preparation methods and specifics about each eating occasion (35). For NHANES 2003–2004, 2 d of data were collected: the first day of intake was collected by using the computer assisted, in-person interviewer-administered 24-h recall, and the second days’ intake was collected by using a telephone-administered (computer-assisted) survey. Because of differences in data collection methods, only the first day of intake was used.

Analyses were completed by using SAS (v.9.1.3; SAS Institute Inc, Cary, NC) and Stata (v.9.2; Stata Corp LP, College Station, TX). We weighted means to be nationally representative, and adjusted the standard errors to account for the stratified and clustered sample design. Data are presented as means per year for Americans aged 2 y and older, with significance set to the $\alpha = 0.01$ level. Trends for Americans aged 2–18 y versus 19 y and older did not differ; thus, results for all ages are combined.

**RESULTS**

**Availability of HFCS in our food supply**

When it was initially introduced in the 1970s, HFCS represented <1% of all caloric sweeteners available for consumption in the United States. Replacement of sugar and other sweeteners with HFCS increased rapidly in the 1980s, however, and by 2004 HFCS (of any kind) represented 42% of all caloric sweeteners (Table 1; 23, 36). Initially, HFCS-42 was the only HFCS

<table>
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<th>Year</th>
<th>Total caloric sweetener</th>
<th>HFCS as a percent of total sweetener</th>
<th>HFCS from HFCS-42</th>
<th>HFCS from HFCS-55</th>
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<td>105.4</td>
<td>0.5</td>
<td>100</td>
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<td>1975</td>
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<td>4.3</td>
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<td>16.8</td>
<td>106.4</td>
<td>15.8</td>
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</table>

*Source: US Department of Agriculture Economic Research Service food disappearance data (36).*
component, but by the early 1980s, HFCS-55 became the major source and represented 59.5% of HFCS used in 2004, down just slightly from its peak use in 2000 (61.9%). Although these data are useful for studying trends, they likely overestimate actual intake. Furthermore, it is important to realize that although HFCS represents roughly 40% of the per capita caloric sweeter consumed in the United States, this proportion is significantly greater in selected foods and beverages.

### Trends in HFCS availability

Data on the availability of HFCS, free fructose, and total fructose are shown in Figure 1 (37). These data were compiled by the USDA Economic Research Service; the HFCS data are those from Table 1. Total fructose is defined as the sum of free fructose plus fructose contained in the disaccharide sucrose (assumed to be 50%). Free fructose is defined as the monosaccharide in HFCS plus other small amounts found in honey (assumed to be 38.5%), for example. Total fructose has changed relatively little over the past 34 y compared with the change in HFCS availability. Since 1970, total fructose availability has increased nearly 18%, from 45.7 to 53.7 g per capita per day, whereas HFCS availability increased from 0.5 to 52.4 g per capita per day over the same time period. Availability of both total and HFCS appear to be slightly declining since 2000, although the continued direction of the trend is difficult to predict.

### Consumption of total added sugar and HFCS

Between 1977 and 2000, consumption of added sugar increased until a slight decline between 2000 and 2004 (Table 2). Added sugar accounted for ≈17% of total energy intake in 2004, up from 15% in 1965 (down from a high of 18% in 2000). Between 1965 and 1977, there was a significant decline in the intake of added sugar, but since 1977 there has been a statistically significant increase (compared with the previous year) in total added sugar and added sugar as a percentage of total carbohydrates consumed. By 2004, added sugar represented almost 32% of carbohydrates for Americans aged 2 y and older.

Between 1989 and 2000, total caloric intake from HFCS jumped dramatically, from 77 kcal per person per day to 189 kcal per person per day (Table 2). At its peak in 2000, HFCS represented 9% of total energy intake and 16.5% of total carbohydrate consumption among Americans. Between 2000 and 2004, there was a small (10 kcal per person per day), although not statistically significant, decline in the estimated caloric intake from HFCS. Despite this slight decline, HFCS still accounted for 8.3% of total energy intake and 15.7% of total carbohydrates consumed in 2004.

These trends were similar between age groups (Figure 2). Calories from added sugar decreased from 1965 to 1991, but then increased significantly between 1991 and 2000. The greatest changes were observed among those aged 2–18 y and 19–39 y: declines of 49 and 52 kcal per person per day, respectively, with a subsequent increase of 164 and 217 kcal per person per day, respectively. At each time point, these age groups have had the greatest caloric intake from added sugar. By 2004, intake of added sugar had leveled off or had begun to decline slightly. Consumption of HFCS increased considerably between 1991 and 2000, with the largest change (172 kcal per person per day) among 19–39-y-olds. Americans aged 2–5 and >60 y had the lowest increase in consumption. HFCS intake in these age groups remained stable from 2000 to 2004, whereas there was a slight decline over this same period in the 2–18 and 19–39 y old age groups.

### Added sugar and HFCS from beverages

Nearly all beverages, save vegetable juice, unsweetened coffee, unsweetened tea, and water (data for these beverages are not shown), were estimated to contain at least some amount of HFCS. For all beverages, there was a trend of increased per capita caloric consumption from HFCS between 1989–1991 and 2004.
By far, fruit drinks and soft drinks accounted for the greatest caloric intake of HFCS, providing 40 kcal per person per day and 158 kcal per person per day, respectively (Figure 3). These values represent an increase of 18 kcal from fruit drinks and 82 kcal from soft drinks over a 15-y period. As a percentage of total energy, soda represented nearly 7% of per capita energy intake and 13% of energy from carbohydrates among Americans aged 2 y and older. Increases in other beverages also occurred, although these beverages accounted for a smaller proportion of calories. For example, in 1989–1991, HFCS from sports drinks provided 1 kcal per person per day; this figure increased to 3 kcal in 2004 (Figure 4). Nearly 10 kcal of HFCS was consumed from sweetened tea in 2004, up 6 kcal from 1989–1991 values.

There was a trend of increased caloric intake from added sugar obtained from beverages between 1989 and 2004. Aside from the obvious contributors—soda and fruit drinks—many additional beverages provided a sizeable number of calories from added sugar (Figure 4). Sweetened tea, for example, was estimated to provide roughly 14 kcal per person per day in 2004, an increase of 7 calories since 1989. Sports drinks, which also accounted for roughly 3 calories of HFCS in 2004, accounted for 4.5 calories of added sugar, up 4.4 calories from 1977. High-fat milk (including chocolate milk) accounted for an additional 5 kcal per person per day. In 2004, alcohol and sweetened coffee were estimated to account for an additional 3 kcal per person per day collectively (data not shown).
Added sugar and HFCS from foods

We assume that HFCS was introduced into food manufacturing in the early to mid 1990s. Thus, we estimated HFCS consumption from foods starting with the NHANES 1999–2000 survey. Certain food groups showed the largest differences in estimated HFCS by use of the 2 estimation techniques. A comparison of the estimates for these food groups is shown in Figure 5.

In general, the contribution of HFCS to caloric intake from various food groups remained relatively stable between 2000 and 2004. However, compared with the caloric contribution of HFCS from soda and fruit drinks, foods provided considerably fewer calories from HFCS overall. Desserts (including pudding, cakes, cookies, and pies) provided the greatest percentage of total energy (=1%) and percentage of carbohydrates (=3%) each year (Figure 3). Total calories from HFCS in desserts declined slightly between 2000 and 2002, but then increased to 29 kcal per person per day by 2004. By far, desserts provided the largest source of calories from HFCS; almost 94% more calories compared with the next highest food groups, ready-to-eat cereals and breads (including bread, bagels, tortillas, biscuits, and muffins), which accounted for roughly 2 kcal per person per day of HFCS each in 2004 (Figure 5). Certain fast food groups (ie, hamburgers and cheeseburgers) also provided a small number of calories of HFCS (Figure 4), although this accounted for an insignificant

FIGURE 4. Calories of high-fructose corn syrup (HFCS) and added sugar from selected food and beverage groups. Data are from the Nationwide Food Consumption Survey 1965 (beverages and foods, n = 13 549), Continuing Survey of Food Intake by Individuals 1989–1991 (beverages, n = 14 689), and National Health and Nutrition Examination Surveys 1999–2000 (foods, n = 8 173) and 2003–2004 (beverages and foods, n = 8 275); results use survey designs to account for clustering and are weighted to be nationally representative.

FIGURE 5. Range of high-fructose corn syrup (HFCS) in selected food groups derived from 2 methods of estimation: the Nutrition Coordinating Center (NCC) method (measured fructose values) and the Glinsmann method (HFCS availability data). The left-hand axis refers to estimated calories of HFCS from cereal, breads, snacks, and dressings only. The right-hand axis refers to estimated calories of HFCS for desserts only.
proportion of total energy intake in all 3 y (<1% of total energy intake).

Although HFCS does not appear to contribute meaningful amounts to per capita caloric intake from many foods, added sugar is estimated to provide considerably more calories. Within food groups, the overall trends in added sugar consumption are not as clear as the trends within beverage groups. For example, the per capita daily caloric intake of added sugar from snacks increased from 1965 to 2000 (2.3 kcal per person per day) but then decreased slightly to 2 kcal per person per day in 2004 (Figure 4). Similar trends were observed for cereal (Figure 4), salad dressing (data not shown), and dairy food groups (data not shown). There was an increase in calories of added sugar from these foods between 1965 and 2000 (2022 for dairy), followed by a leveling off or slight decrease by 2004.

Desserts (Figure 3) provided significantly more calories from added sugar compared with any other food group, although trends were not consistent: per capita daily calories decreased by 36 calories from 1965 to 2000 (not shown), increased by 20 calories to 74 calories between 1991 and 2000, and decreased again by 7 calories in 2004. Similar cyclical trends were observed for breads (Figure 4). Interestingly, breads accounted for considerably more calories of added sugar in 1965 than did cereals, but by 2004, these 2 food groups contributed equally to per capita energy intake from added sugar. Overall, however, foods accounted for ≤1% of total energy and <1% of total carbohydrates, save cereal, breads, and desserts, which accounted for between 1% (cereal) and 6% (desserts) of total carbohydrates in 2004.

Estimates among consumers

Among consumers, caloric intake from added sugar and HFCS among the top foods and beverages was considerably greater than per capita estimates (Table 3). For example, although a relatively small (10%) percentage of persons reported consuming sweetened tea, sweetened tea provided an estimated 134 kcal per consumer per day compared with an estimated per capita amount of 14 kcal per person per day from added sugar (95 kcal per consumer per day versus 10 kcal per capita per day from HFCS). Likewise, 24% of cereal consumers obtained 40 more calories (53 versus 13) from added sugar than the per capita estimates, and for the 46% of reported soda consumers, there was a 98% increase in energy from added sugar (as HFCS). Per capita and per consumer estimates did not differ greatly for breads.

Distribution of added sugar is important

There were important differences in calories from added sugar among those in the top 20% of the caloric distribution (Table 4). In 1965, the highest quintile consumed an average 640 more kcal per person per day from added sugar than the lowest quintile. This discrepancy had increased to 840 kcal per person per day in 2004. Between 1965 and 2004, calories of added sugar from beverages increased by 158% within the top quintile (393 kcal per person per day difference from 1965 to 2004) of the distribution, but calories of added sugar decreased by 28% (−163 kcal per person per day difference from 1965 to 2004) from foods.

With respect to beverages, persons in the lowest quintile (Q1) of the population consumed zero calories of added sugar, and although the bottom 60% of the distribution (Q1 to Q3) increased caloric intake from added calories, persons in the upper 2 quintiles (Q4 and Q5) appeared to be driving the overall trends (Table 4). Similar differences between the highest and lowest quintiles were observed within foods; however, persons at the lowest end (Q1) of the distribution obtained some calories from added sugar (20 kcal per person per day in 2004). Between 1965 and 2004, the trend in for consumption of added sugar from foods all quintiles appeared to be decreasing (Table 4).

Total caloric intake from HFCS increased almost 100% to 505 kcal per person per day between 1989–1991 and 2004 among the top 20% of the population. Similarly to added sugar, the overall trends were driven by the top quintiles; persons in the top 60% of the population increased caloric intake from HFCS, whereas those in the bottom 40% decreased caloric intake from HFCS slightly between 1989–1991 and 2003–2004. Beverages provided 450 calories of HFCS to persons in the top 20% of the population and zero calories to those in the lowest 20%. Everyone consumed at least some calories of HFCS from foods (3 versus 122 kcal; data not shown).

DISCUSSION

Consumption of added sugar, generally, and HFCS, specifically, has been hypothesized as a contributing factor to the rising rates of obesity observed over the past few decades. Mechanistically, this hypothesis is based on differences in the rates of digestion and absorption between fructose and glucose (38–41) and the observation that increased consumption of sugar-sweetened beverages is associated with weight gain over time (15, 42–44). These topics are beyond the scope of this article, but are addressed elsewhere in this supplement. The purpose of this article was to examine the trends and patterns in HFCS and added sugar consumption in both beverages and foods.

We report that daily per capita intake of calories from HFCS and added sugar has followed a general upward trend since the mid-1960s. Despite a drop in sugar consumption between 1965 and 1977, added sugar accounted for 17% of total daily energy intake and 32% of total carbohydrate intake among Americans aged 2 y and older. These values represented an increase of 31% (from the lowest value in 1977) and 23% (from the lowest value in 1991), respectively. The trend in HFCS consumption has been steadier; between 1991 and 2000 there was a 120% increase in calories from HFCS, and since 2000, calories from HFCS have remained relatively stable. These values represented 8.5% of total energy and 15.9% of carbohydrates in 2004—an increase of 67% and 57%, respectively, from estimated intake in 1989.

Our results are consistent with those reported elsewhere by our research team. In a study examining worldwide shifts in added sugar availability and consumption, Popkin and Nielsen (45) reported an increase from 235 calories from added sugar in 1977 to 318 calories from added sugar in 1996. Similar trends in the number of calories from added sweetener by food group were also reported. Using the same Glinsmann method as reported here, Bray et al (10) examined HFCS consumption between 1977 and 1998 for a select set of food groups, namely soft drinks, fruit drinks, and desserts. As reported in our article, Bray et al found a general increasing trend in added sugar and HFCS consumption from the 3 food sources they examined. The present study expanded on these results by estimating HFCS contribution to caloric intake from numerous additional food sources over a longer time period.

The patterns we have observed are also consistent with recent literature on trends in the location and types of foods being
consumed. Between 1977 and 1996, salty snacks, pizza, and sugar-sweetened beverages showed the largest increases in consumption among all age groups, but the largest changes were observed in the younger (2–18 and 19–39 years) age groups (46). Location of energy consumption is also shifting, with energy from fast food places and restaurants replacing energy consumed at home (46). Furthermore, people reported that foods that can be easily obtained from these food sources (e.g., hamburgers and cheeseburgers) were almost exclusively consumed away from home, which suggests that the types of foods prepared at home have shifted (46).

Our study shows that calories from added sugar and HFCS from similar types of foods (e.g., hamburgers, snacks, sodas) has continued to rise, or at least has reached a plateau, since 1996.
Our article has several limitations. First, because of the lack of available data, the amount of HFCS in foods had to be estimated. Because little work has been done to estimate HFCS intake, we used 2 different estimation methods—one based on availability (Glinsmann method) and one on measured fructose (NCC method) in foods. For some key food groups, these methods resulted in significantly different estimates (eg, the desserts food group). These differences are likely the result of differences between the 2 estimation techniques, each of which required acceptance of certain assumptions.

With respect to the NCC (measured fructose) method, a direct measure of fructose was not available for all foods reported on the USDA database; linkage codes between NCC and USDA data were available for only \( \approx 1000 \) foods. For foods for which no direct link was possible, we applied an average fructose value (based on the food group to which that particular food was assigned), that likely resulted in a misestimation of fructose, and HFCS, for many foods. However, it is impossible to predict the direction of this misestimation for any individual food or beverage item. To reduce misestimation, we grouped foods according to their added sugar content. However, within some food groups, a large range of added sugar and fructose would result in a dilution of average values within a food group. Additionally, for some foods from NHANES 2003–2004, direct measures of added sugar were not available. For these foods, we applied sugar values from the closest matching 8-digit USDA food code from the previous time point (NHANES 2001–2002).

When there were no comparable foods in previous USDA files (eg, Propel Fitness water; Gatorade, Chicago, IL), we used nutritional information provided by the manufacturers and calculated added sugar values from this information. Our estimates of HFCS consumption using the Glinsmann Method are based on availability of data from the mid-1980s; they are likely to underrepresent HFCS availability within these sectors today.

Second, our data are limited by differential collection methods between exams and differential time spans over which data were collected. The first 3 exam periods (1965, 1977, and 1989–1991) covered \( \approx 15 \) y, whereas the last 3 periods (1999–2000, 2001–2002, and 2003–2004) covered just 5 y, which may not have been long enough to observe sensitive changes in consumption patterns. To create more comparable time spans between studies, we combined the NHANES data into a single survey and reexamined trends. Although the trends in added sugar were slightly clearer with use of the combined surveys, HFCS could not be estimated (recall that HFCS was not widely used in food products until the late 1990s). Thus, we elected to keep each NHANES survey separate. Some of the differences in observed consumption may also have been due to changes in data collection methods. In 2000, the automated multiple pass method was used for dietary collection. This tool is designed with internal prompts to help decrease the incidence of underreporting, thereby increasing the accuracy of data collection. Although this may result in an increase in reporting frequency of foods and beverages, it is unlikely to account for the large changes reported here.

In general, the availability and consumption of HFCS and added sugar has increased over the past 3 decades. We report that the types of foods and beverages contributing to daily energy intake from HFCS have shifted over the past several decades: desserts accounted for roughly 4% of total energy intake in 1965.
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This number dropped to 3% by 2004, whereas soda accounted for 6.8% of total energy intake in the same year. Although sweetened beverages, such as soda and fruit drinks, currently account for the largest proportion of energy from HFCS, we report that other beverages (sports drinks) and foods (dishes, breads, and ready-to-eat cereals) are also contributing considerable amounts of per capita energy intake. These are foods that are often consumed as snacks rather than meals (37, 46), so ultimately, it seems that HFCS (and other added sugar) is not what ‘s for dinner, it’s what’s in addition to dinner. (Other articles in this supplement to the Journal include references 47–50.)

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The authors’ responsibilities were as follows—BMP and KJD: organized the study concept and design and participated in data acquisition, interpretation of results, and in preparation of the manuscript; KJD, in collaboration with PB, and under the guidance of BMP: conducted statistical analysis. None of the authors had any conflicts of interest to report.

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