Dietary Fructose Consumption Among US Children and Adults: The Third National Health and Nutrition Examination Survey

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Abstract

Introduction

Fructose is a monosaccharide that is found naturally in only a few foods, primarily fruits. It is typically consumed as sucrose (table sugar), a disaccharide composed of equal parts of fructose and glucose, or as a component of high-fructose corn syrup (HFCS). HFCS can be mixed to varying concentrations of free fructose and free glucose. According to US Department of Agriculture (USDA) data, 60% of HFCS used is 55% fructose and the remainder is typically 42% fructose.[1] HFCS and sucrose are both commonly added as sweeteners to many processed foods and beverages. HFCS use has increased compared with that of sucrose because it is relatively inexpensive and has useful properties, including sweetness, flavor enhancement, freezing point depression, and shelf-life extension through improved moisture control.[2]

Fructose occurs as an intermediary in glucose metabolism but is not an essential nutrient for human metabolism. When consumed alone, fructose is poorly absorbed from the digestive tract.[3] Absorption improves when fructose is consumed in combination with glucose and amino acids.[3]. After absorption, fructose is quickly cleared by the liver, resulting in minimal elevation of peripheral blood levels.[4] Hepatic metabolism of fructose bypasses the rate-limiting steps central to glucose metabolism and can result in increased glycogen deposition, de novo lipogenesis, and lactic acidemia.[4] In animals, chronic fructose ingestion causes features of the metabolic syndrome, including dyslipidemia and insulin resistance as well as obesity.[5–7] While there are no long-term, controlled studies in humans, short-term studies have consistently shown hyperlipidemia and insulin resistance in response to fructose concentrations ranging from 7.5% to 25% of total kcal per day.[8–11]

USDA food disappearance data suggest that total daily caloric intake in the form of sweeteners has increased from an estimated 402 calories per capita in 1970 to a peak of 510
calories in 1999.\[1\] Also using food disappearance data, Elliot and colleagues\[6\] estimated that per capita availability of fructose increased 26% from 64 g/day in 1970 to 81 g/day in 1997. While disappearance data can provide a useful estimate of the proportional contribution of a food item to the food supply over time, it does not accurately differentiate between what is consumed and what is lost in distribution or food processing, for example. It also does not provide information on the population distribution of intake.

Fructose consumption patterns among Americans have not been well-described, in part because of the lack of a fructose variable in most nationally representative surveys. In 1993, researchers at the US Food and Drug Administration (FDA) used USDA Nationwide Food Consumption Survey data collected in 1977 to 1978 and a sugars content database (which they developed) to estimate fructose intake. They determined that the mean intake of fructose was 37 g among all Americans, and even higher (54 g) among those age 15–18 years.\[12\] Also using the Nationwide Food Consumption Survey 1977–1978 and the Continuing Survey of Food Intakes by Individuals (CSFII), 1989–1991 and 1994–1998, Bray et al\[13\] estimated total fructose intake for the US population by calculating 50% of sucrose and adding estimated fructose from HFCS. They calculated the HFCS amount by creating a food category-wide estimate of the proportion of caloric sweetener that was HFCS and then applying this conversion technique to the relevant food groups found in the survey database.\[13\] Using these methods, Bray and colleagues estimated that total fructose intake for Americans 2 years of age and older was increased from 8.8 % in 1977–1978 to 9.4% for 1989–1991 and to 11.5% for 1994–1998. While this method provided an estimate of the increased intake in the population, it did not allow reporting of distribution of fructose consumption by source or demographics.

The purpose of this paper is to provide a more detailed description of fructose intake based on individual reports of dietary intake among the US population from the National Health and Nutrition Examination Survey, 1988–94 (NHANES III), the only nationally representative survey in the past 20 years to have included fructose content as a reported variable.

**Methods**

**Terminology**

The following definitions will be used throughout this paper. Similar to the paper by Park and colleagues,\[12\] we defined sugar as any free mono- or disaccharide present in a food or beverage. Sugar-sweetened beverages are defined as beverages containing added sugar from any source, including cane sugar, HFCS, and other sweeteners. Fructose refers to both the free and bound forms of fructose.
**Study Population**

We analyzed data from NHANES III collected from 1988 to 1994. NHANES uses a stratified, multistage, probability cluster sample representative of the US civilian, noninstitutionalized population ≥ 2 years. Data were collected by the National Center for Health Statistics, Centers for Disease Control and Prevention (CDC), via household interviews and physical examinations at a mobile examination unit. Detailed descriptions of the NHANES III plan, operation, and sample design are published elsewhere.[14–16] The survey was approved by the CDC Institutional Review Board, and written consent was obtained from all participants.

**Dietary Data**

A single 24-hour dietary recall, administered by a trained dietary interviewer, was used to assess intake on all respondents. Respondents were asked to think about their diet over the past 24 hours and to report consumption of all foods and beverages consumed during the previous 24 hours (midnight to midnight) using a computer-assisted, automated technique. Proxy respondents reported for children aged 2 years to 11 years.[15] A second 24-hour recall was administered to a randomly selected subsample of 1198 persons by telephone. In NHANES III, fructose intake was calculated by linking each food consumed to the fructose-content variable in the University of Minnesota's Nutrition Coordinating Center (NCC) Food and Nutrient Database.[16] The NCC database uses the USDA Nutrient Data Laboratory as the primary resource of nutrient data.[17] For missing values, fructose content is obtained from food manufacturers, scientific literature, other published food tables, and occasionally unpublished analytic data. Standardized, published imputation procedures are used when information is not available from any of these sources.[17]

**Covariates**

Fructose consumption patterns were determined for groups defined by sex; age in years (2–5, 6–11, 12–18, 19–30, 31–50, 51–70, and ≥ 71); race/ethnicity (non-Hispanic white, non-Hispanic black, Mexican American, and other); poverty-income ratio (1.3 or less, 1.3–3.5 or less, and > 3.5); and body mass index (BMI [kg/m²]). Stature and weight were measured as part of a standardized physical examination.[15] BMI was used as a measure of weight adjusted for stature. Adults were classified as normal weight (BMI 18.5–24.9), overweight (BMI 25.0 to 29.9), or obese (BMI ≥ 30.0).[18] Children and adolescents whose sex- and age-specific BMI was ≥ 85th to < 95th percentile were categorized as at risk for overweight; those with BMI ≥ 95th percentile were included in the overweight group according to the 2000 CDC growth curves.[19]

**Analytic Sample**
We confined our analysis to 27,300 nonpregnant, nonlactating adults and children 2 years of age and older. Of these, 4955 (16.3%) were excluded due to missing dietary data, because reported intake was implausible (total energy < 475 kcal or > 6000 kcal), or because the amount of food was not usual for the respondent. In addition, those who were underweight (BMI < 3rd percentile for age and sex for those 2–19 years and BMI < 18.5 for those 19 years and older, n = 784 [2.9%] or missing BMI, n = 303 [1.1%]) were excluded. Some participants were excluded based on more than one criteria, yielding a final analysis sample of 21,483. The sample was evenly divided between males and females. Three fourths were non-Hispanic white, 11% were non-Hispanic black, and 6% were Mexican American. A total of 28.7% were overweight, and 19.8% were obese. Those excluded from the analysis tended to be younger than those included (mean age, 27.1 years and 36.5 years, respectively, \( P < .0001 \)). They were also more likely to be non-Hispanic black (17.0% vs. 11.0%). More of those excluded were in the lowest income level (poverty income ratio \( \leq 1.3 \)) than among those included (26.7% vs. 19.6%, respectively).

**Analysis**

We estimated fructose intake as follows: total fructose intake in grams; percent of total energy intake, percent of total carbohydrate intake, and percent of total sugar intake from fructose; and the percent of total fructose intake from each of the USDA food groups. Total fructose intake was calculated by summing the intake from all food sources per individual. Percentage of intake as fructose was calculated as: percentage of total energy from fructose \( \left( \frac{\text{kcal from fructose}}{\text{total kcal intake}} \right) \times 100 \); the percentage of total carbohydrate from fructose \( \left( \frac{\text{kcal from fructose}}{\text{kcal from carbohydrate}} \right) \times 100 \); and the percentage of sugar from fructose \( \left( \frac{\text{kcal from fructose}}{\text{kcal from sugar}} \right) \times 100 \). To identify the major sources of fructose intake, we grouped the contribution of different USDA food groups to the total fructose intake as the grams of fructose from food group/total grams of fructose*100. These USDA food groups included nonalcoholic (sugar-sweetened) beverages, grains (included bread and pasta, cakes, pies, pastries, and cereals), whole fruit and fruit juices, sugars and sweets (included candies and confections), vegetables, and dairy products. We grouped fructose-containing foods and beverages from other USDA food groups together in a category that we refer to as “other.” In further analysis, grains were divided into subgroups of ready-to-eat (RTE) cereals, bread/pasta, and cakes/pies/snacks and whole fruit and fruit juice intake were examined separately.

As some of the outcomes examined were not normally distributed due to a high number of zero values, medians and \( t \)-tests on medians were produced and compared with the means and tests for differences between means. While some of the median outcomes were lower in value than the means, the patterns and test results were similar. Therefore, for ease of interpretation, means and results of \( t \)-tests are presented. Also, because we were making
multiple comparisons for each outcome, we calculated the Bonferroni critical \( P \) value as <.0036. \( P \) values exceeding that cutoff should be interpreted with caution as they may represent a type II error. Where there were \( P \) values that followed a trend or pattern within subgroups, we considered a value <.05 significant. Models for total fructose intake in grams were adjusted for total energy intake.

To account for the complex sampling design and to estimate weighted findings that reflect the probability of selection, nonresponse, and poststratification adjustments, we used SAS-callable SUDAAN (versions 9.1, and 9.0, respectively) (SAS, Cary, North Carolina; SUDAAN, Research Triangle Park, North Carolina).

## Results

### Fructose Intake

The mean fructose intake was 54.7 g. The mean by age group ranged from 38.4 g to 72.8 g (Table 1), which was an average of 10.2% of total calories consumed. Males tended to consume more than women in absolute terms (63.4 g vs. 46.2 g, respectively, which is not significant when adjusted for total energy intake), but slightly less in proportion to total calories (10.0% vs. 10.5%; \( P < .01 \)) (Table 1). Adolescents aged 12 to 18 years consumed the most fructose (72.8 g/d; 12.1% of total calories), significantly more than 31- to 50-years-olds (\( P < .001 \)). Fructose consumption was higher among non-Hispanic blacks (57.7 g; 11.0% of total calories) than among other race/ethnicities (49.3 g to 55.0 g). Overall, normal-weight participants consumed more fructose than obese persons (56.2 g vs. 51.1 g; 10.6% vs. 9.8% of total calories), respectively. However, in adults age 19 to 30 years, fructose consumption was significantly higher in obese individuals (71.9 g, 11.9% of total kcal) than in normal-weight individuals (63.9 g, 10.5% of total kcal) (\( P \) value for difference in grams, 0.0004; \( P \) value for difference in percentage of kcal, 0.0035 [data not shown]). Those in the highest income category consumed less of their total calories from fructose than those in the lowest income category, 9.7% vs 10.6%, respectively (\( P < .001 \)).

![Table 1](image.png)
Mean\textsuperscript{1,2} (se) Total Fructose Intake (g), Percent of Total Energy From Fructose, Percent of Total Carbohydrate From Fructose, and Percent of Total Sugar From Fructose, NHANES III\textsuperscript{3} (n=21,483)

Fructose comprised 19.7% of the total carbohydrate intake (Table 1). The highest percentage was observed in adolescents (12–18 years; 22.4% of their carbohydrate intake), but all age groups between 2 and 30 years consumed a significantly larger percentage of carbohydrate from fructose compared with 31- to 50-year-olds. Persons older than 50 years consumed significantly less carbohydrate from fructose than the 31- to 50-year-olds (P < .001). Non-Hispanic blacks consumed a higher percentage of carbohydrate from fructose than did non-Hispanic whites (P < .01). Fructose comprised 40.9% of the total sugar consumed. The highest percentage was observed in the 19- to 30-year age group (42.5%), which was significantly higher than the 31- to 50-year-old age group (41.4%) (P < .01). The youngest age groups (2–5 years and 6–11 years) and the oldest age groups (51–70 years and 71 years and older) also consumed a higher percentage of sugar from fructose than 31- to 50-year-olds (P < .01). All race/ethnicity groups consumed a higher percentage of sugar from fructose than did non-Hispanic whites (40.4%) (P < .001).

Table 2 shows the percentile distribution of the percentage of total energy from fructose. The 75th percentile for kcal per day from fructose was 13.3% of total calories, the 90th percentile was 17.2%, and the 95th percentile was 19.5%. These upper quantiles were highest among adolescents age 12 to 18 years: 15.1%, 18.9%, and 21.5%, respectively. The upper quantiles were lowest among those 71 years of age and older: 12.1% (75th percentile), 15.2% (90th percentile), and 17.1% (95th percentile). By racial ethnic group, the upper quantiles were highest among non-Hispanic blacks. The 75th percentile was 14.1%, the 90th percentile was 17.9%, and the 95th percentile was 20.7%. These upper quantiles were lower among non-Hispanic whites and Mexican Americans, and lowest among the “other” ethnic group, in which the 75th percentile was 12.4%, the 90th was 15.5%, and the 95th was 18.3%.

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Table 2
Percentiles of Total Calories Consumed as Fructose (% of total energy)\textsuperscript{1}

Fructose Sources
Overall, the most important contributors of fructose were sugar-sweetened beverages, 30.1%; grains (which includes processed foods, such as cakes, pies, and snacks as well as breads and cereals), 21.5%; and fruit or fruit juices, 19.4% (Table 3). Sweets contributed 10.8% to total fructose intake. Sources of fructose differed by age group, race/ethnicity, and income. In very young children (age 2–5 years) and older adults (age 51 years and older), fruit and fruit juice supplied over 25% of fructose, which was significantly higher than in 31- to 50-year-olds (16.3%) (P <.01). In adolescents (age 12–18 years) and young adults (age 19–30 years) sugar-sweetened beverages provided almost half of the fructose consumed (45.2% and 43.9%, respectively), which was significantly higher than in 31- to 50-year-olds (30.0%) (P <.001). Older age groups (51 years and older) consumed a smaller percentage of their total fructose from sugar-sweetened beverages than 31- to 50-year-olds (51–70 years, 18.2%; 71 years and older, 10.9% [P <.001]). While they were the most important source for all race/ethnicities, sugar-sweetened beverages contributed substantially more of the fructose consumed by non-Hispanic blacks and Mexican Americans, approximately 40%, compared with non-Hispanic whites, 28% (P <.001).

Those in the highest income category consumed fructose from beverages, grains, and fruit or fruit juices in almost equal amounts (approximately 22% of total calories from each) compared with 35.6%, 18.0%, and 19.4%, respectively, among those in the low-income group (P<.01). Figures 1, 2, and 3 illustrate the importance of some food groups and subgroups to fructose intake among young children, adolescents, and adults. While sugar-sweetened beverages are clearly the most important source of fructose among all age groups, the importance of food subgroups varies by age. Among young children, RTE cereal and dairy products contribute 6% each to total fructose intake, while whole fruit contributes 19% and 100% fruit juice 10%. Adults acquire less fructose from sugar-sweetened beverages and more from whole fruits.

**Figure 1**
Contribution of food groups and subgroups to total fructose intake (%) among children age 2–5 years. Two food groups were subdivided into subgroups. * Foods from the grains group were divided into RTE cereal, bread/pasta, and cakes/pies/snacks. ...
Contribution of food groups and subgroups to total fructose intake (%) among adolescents age 12–18 years. Two food groups were subdivided into subgroups. *Foods from the grains group were divided into RTE cereal, bread/pasta, and cakes/pies/snacks. ...

Figure 3
Contribution of food groups and subgroups to total fructose intake (%) among adults 19 years of age and older. Two food groups were subdivided into subgroups. *Foods from the grains group were divided into RTE cereal, bread/pasta, and cakes/pies/snacks. ...

Table 3
Mean (se) Percent\(^1, 2, 3\) of Total Fructose From Food Sources, NHANES III\(^4\) (n=21,483)

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Discussion
In our study of free-living American children and adults, we found that fructose consumption represented a significant source of calories for most individuals in 1988–1994. Specifically, we found that the mean intake of fructose was 54.7 g. This is an increase of almost 50% from that estimated by Park and colleagues using data from 1977–1978. Our analysis shows that fructose represents more than 10% of caloric intake for the total population. This percentage is slightly higher than the 9.4% reported by Bray and colleagues; however, their estimate did not include naturally occurring fructose, such as that in fruit and fruit juice. [13]

Measurement of fructose consumption is important because growing evidence suggests that it may play a role in health outcomes. Short-term studies have shown that fructose can elevate plasma triglycerides. In a 24-hour study of healthy adults given sugar-sweetened beverages with meals, plasma triglycerides were significantly elevated after fructose compared with glucose, and this effect persisted even at 12 hours after consumption of the fructose beverage. [10] Faeh and coworkers [20] showed that healthy men doubled their
mean fasting triglycerides after 6 days on a diet consisting of 25% energy from fructose. In a longer study, Bantle and coworkers reported a 32% increase in triglycerides after 6 weeks of a diet consisting of 17% fructose.\textsuperscript{[21]}

While no fructose-feeding studies to evaluate triglycerides in children have been published, there are reports of correlations between fructose intake and plasma lipids. In 1980, Morrison and colleagues\textsuperscript{[22]} showed that, in children age 6 to 19 years, dietary sucrose was associated with increased plasma triglycerides and low high-density lipoprotein (HDL) cholesterol. In 12-year-old children in Finland, higher sugar consumption was associated with lower HDL cholesterol.\textsuperscript{[23]} In normal-weight and overweight Swiss children, the only dietary factor that was a significant predictor of smaller low-density lipoprotein (LDL) particle size was total fructose intake.\textsuperscript{[24]} Small LDL particle size has been linked to increased risk for cardiovascular disease.\textsuperscript{[25]}

Most of these short-term trials studied higher intake of fructose than were observed in our data. Although there is not enough information on how fructose consumption correlates with metabolic complications over the long-term, we suspect that there may be a threshold level for effects of fructose. No elevation of fasting triglycerides was seen in adults when 12% of energy was provided as fructose for 12 weeks\textsuperscript{[26];} however, at 17% for 6 weeks\textsuperscript{[21]} and 25% of energy intake for 10 weeks,\textsuperscript{[8]} significant increases in triglycerides were found. Hallfrisch and colleagues\textsuperscript{[11]} demonstrated a significant increase in plasma total and LDL cholesterol after consuming a diet of 7.5% and 15% of calories from fructose. In an earlier article, the same group showed that total fasting triglycerides increased significantly in males but not females as the level of sucrose increased in the diet from 5% to 18% to 33%.\textsuperscript{[27]} The highest level, 33%, would provide 16.5% of calories as fructose (half of the sucrose). Our analysis shows that over 10% of the NHANES III population surpass this level.

Much attention has focused on sugar-sweetened beverages as a possible source of excess calories. We found that these beverages provide nearly half of the fructose consumed by adolescents (12–18 years) and 30% of fructose for all age groups. Grains (including breads, cereal, cakes, pies, and snacks) were the second-largest source. Breads and cereals alone contributed 12% in children (2–18 years) and 11% in adults. In the very young (2–5 years) and older adults (> 51 years), the category “fruits and 100% fruit juice” was the single largest source of fructose. Notably, for our cohort, if all sources of fructose were eliminated other than whole fruit and vegetables, children and adults would eliminate 82% and 75% of fructose, respectively. Our analysis confirms that fructose is prevalent in the American diet and that processed foods in all categories are substantial contributors.

Strengths of our study include that intake estimates were made using dietary data collected from a nationally representative sample. In addition, the availability of data on key
demographic and anthropometric indicators enables us to describe fructose consumption patterns across groups. A limitation of our analysis is the availability of only one 24-hour recall with which to assess dietary intake, although the large sample size and the high propensity to consume fructose enables us to use 1 day’s intake to estimate the mean consumption of the population.[28] To further justify the use of 1-day of dietary recall, we tested for differences in the mean fructose intake between the subsample with two 24-hour recalls and a single recall. We found no significant differences in mean fructose intake ($P = 0.38$). As the nutrient database used by NHANES for this study differs from that used by Park and coworkers in their 1977–1978 study of a representative sample of Americans’ fructose intake,[12,16] our ability to compare the results of these studies may be limited.

True fructose consumption may be higher than we report due to the systematic bias created by underreporting.[29] In particular, underreporting of total energy is known to increase as BMI increases. Poppitt and colleagues[30] found no difference in underreporting of macronutrient intake between obese and nonobese women; however, all participants underreported total carbohydrates and added sugar intake. This effect could have led to underreporting of fructose-containing food intake in our analysis and thus an overall underestimation of fructose consumption.

It is also unknown how our data (collected in 1988–1994) compare with current fructose consumption patterns. Although the NHANES III data are older, it is the only nationally representative survey that assessed fructose intake. These data were obtained during a phase of both increasing obesity and total sugar consumption and thus provide important information regarding fructose consumption during a critical period.

Conclusion

We have reported fructose consumption levels and sources in a representative population of Americans. Fructose consumption represented 10% of calories consumed, which is an increase from prior estimates. A total of 74% of fructose came from foods and beverages other than whole fruits and vegetables. Further surveillance and research are needed to assess trends in fructose consumption and to develop a better understanding of the health impact of this common additive in the food supply.

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