The Journal of Nutrition
Supplement: The State of the Science on Dietary Sweeteners Containing Fructose

National Estimates of Dietary Fructose Intake Increased from 1977 to 2004 in the United States[1–4]

Bernadette P. Marriott,[5,7]* Nancy Cole,[6] and Ellen Lee[6]

[5]Abt Associates Inc., Durham, NC 27703; [6]Abt Associates Inc., Cambridge, MA 02138; [7]Department of Nutrition, University of North Carolina Schools of Medicine and Public Health, Chapel Hill, NC 27599

Abstract

Our purpose was to conduct a new analysis to update and extend previously published trends of fructose availability and estimated fructose intake and food sources of dietary fructose from the 1977–1978 Nationwide Food Consumption Survey (NFCS) data. We estimated fructose usual intake with data from NHANES 1999–2004 for 25,165 individuals (1 y and older, excluding pregnant and lactating women and breast-fed infants) using the Iowa State *C-SIDE* software. We applied food group-specific conversion factors to individual measures of sugar intakes following the earlier study. Sweetener availability in the United States increased from 1978, peaked in 1999, and declined through 2005. The high-fructose corn syrup percentage of sweeteners increased from 16% in 1978 to 42% in 1998 and then stabilized. Since 1978, mean daily intakes of added and total fructose increased in all gender and age groups, whereas naturally occurring (N) fructose intake decreased or remained constant. Total fructose intake as percentage of energy and as percentage of carbohydrate increased 1 and 1.2%, whereas daily energy and carbohydrate intakes increased 18 and 41%, respectively. Similar to 1978 results, nonalcoholic beverages and grain products were the principal food sources of added fructose. Fruits and fruit products were the main dietary sources of N fructose in 2004; in 1978, grain products and vegetables were more predominant food sources. Although comparison of estimates of fructose intakes between data from the 1977–1978 NFCS and the NHANES 1999–2004 showed an increase, this increase was dwarfed by greater increases in total daily energy and carbohydrate intakes. J. Nutr. 139: 1228S–1235S, 2009.

Introduction

Many historians and anthropologists have recounted the global history and economic impact of sugar (sucrose). A historical analysis showed that although in 1000 A.D. few Europeans knew of the existence of sucrose, by 1650, it was a pervasive part of medicine, food, and literary images. By 1900, sucrose supplied almost 20% of the energy in the English diet, and, based on commodities information, British use of sugar had increased by 2500% in 150 y (1). Changes in food technology over the last 30+ years have led to a new chapter in the history of sugar, specifically the change in the sweetener composition in the food supply (2).

USDA food availability data indicate the volume of commodities for potential consumption by the U.S. public. Using availability data from 1960 to 1990, Park and Yetley (2) demonstrated that although sucrose was the main sweetener in 1960 (~90% of total sweeteners, dry weight basis), the use of corn sweeteners steadily increased from near zero in 1960 to ~50% by 1985. The shift to corn sweeteners through the early 1970s was mainly from glucose-based sweeteners, but from 1974 to 1985, the increase in corn sweeteners represented a shift from glucose-based sweeteners to high-fructose corn syrup (HFCS).[8] By 1985, HFCS represented ~35% of sweeteners in the U.S. food supply.

[1] Published in a supplement to *The Journal of Nutrition*. Presented at the conference "The State-of-the-Science on Dietary Sweeteners Containing Fructose," held in Beltsville, MD, March 18–19 2008. The conference was cosponsored by the Technical Committee on Carbohydrates of the International Life Sciences Institute North America (ILSI North America) and the USDA, Agricultural Research Service. The views expressed in these papers are not necessarily those of the USDA, the Agricultural Research Service, or the Supplement Coordinators. Supplement Coordinators for this supplement were David M. Klurfeld, USDA, Agricultural Research Service, and Molly Kretsch, USDA, Agricultural Research Service. *Supplement Coordinator Disclosure*: D. Klurfeld and M. Kretsch: no relationships to disclose.
[2] Supported in full by a contract between ILSI North America and Abt Associates Inc.
[3] Author disclosures: B. Marriott, N. Cole, and E. Lee, funding to support travel to the 18–19 March 2008 workshop "The State of the Science on Dietary Sweeteners Containing Fructose" and the writing of this resulting manuscript was provided by the International Life Sciences Institute, North American Branch.
[4] Supplemental Figure 1 and Supplemental Tables 1–9 are available with the online posting of this paper at jn.nutrition.org.
* To whom correspondence should be addressed. E-mail: bernadette_marriott@abtassoc.com.

[8] Abbreviations used: *C-SIDE*, Software for Intake Distribution Estimation; DI, daily intake; FR, fruits and fruit products; G, grain products; HFCS, high-fructose corn syrup; IFF, Individual Food Files; MEC, Mobile Exam Unit; MPED, MyPyramid Equivalents Database; N fructose, naturally occurring fructose; NFCS, Nationwide Food Consumption Survey; USDA ERS, United States Department of Agriculture Economic Research Service; V, vegetables and vegetable products.

First published online April 29, 2009; doi:10.3945/jn.108.098277

These researchers reported that the overall availability of sweeteners changed little from 1970 to 1985; however, the composition of sweeteners changed dramatically. In 1995, others extended this analysis of per capita availability of carbohydrate sweeteners from 1985 to 1992 and reiterated that the total amount of carbohydrate sweeteners remained fairly constant from 1960 to 1992 at 155 ± 2.9 g/d but that the HFCS percentage of the total continued to increase (3). Both reports identified the increase in HFCS availability as primarily resulting from the switch from sucrose to HFCS in sweetened beverages.

This change in type of sweetener availability was of interest because the timing of the increase in availability roughly paralleled the increase in overweight and obesity in the United States. Although some studies indicated that these parallel time frames were strong evidence for causality (4,5), human and animal studies that have focused systematically on the food source of fructose have shown that the issue is much more complex (6–8). Because of proposed correlations between obesity and HFCS in beverages, there has been a sharp increase in human studies focused on fructose intake in sweetened beverages. However, overall experimental data are mixed. Some studies reported a link between sweetened drinks and 1 or more measures of obesity or another health outcome (6–9), yet other reports found no association or less conclusive results (10,11). Still other studies underscored the need to consider the complex nature of changes in intakes. For example, the percentage of 1548 10-y-old children in the Bogalusa Heart Study who consumed sweetened beverages over a 21-y period declined significantly; however, the gram amounts of these beverages did not decrease, and the total energy intake by the study participants remained the same. These authors did not find a linear relation among sweetened beverage consumption and BMI and total energy intake, although BMI significantly increased over the period (12). Nonetheless, of sugars added to foods, fructose is the most often cited as a potential contributing factor to the increase in overweight because it has become the major sweetener in bread products and soft drink beverages.

In 1993, Park and Yetley (2) published nationally representative estimates of fructose intake in the U.S. diet. Fructose in food can be naturally occurring or added during food processing. To estimate fructose intake, they included the fructose found in foods (free fructose) and the fructose released from sucrose during digestion (bound fructose) (2). This study was based on dietary recalls from the 1977–1978 Nationwide Food Consumption Survey (NFCS). The NFCS and food composition databases that were associated with it did not contain measures of specific types of sugars in foods, such as sucrose and fructose. To estimate fructose intake, the 1978 NFCS data were combined with external food group-specific conversion factors (13). More recent reviews and updates of fructose intake have continued to use the same food group-based approach because there are no current values for fructose in the food supply that can be directly linked to present national food intake surveys (3,4).

This study sought to update and extend the 1993 analysis of Park and Yetley (2) by *1*) lengthening the trend analysis of the availability of sweeteners and food sources of fructose from 1990 to 2005 and *2*) estimating mean daily intakes (DI) of fructose in the United States using the NHANES 1999–2004 dietary intake data.

Methods

Fructose availability. USDA food availability data indicate the volume of commodities for potential consumption by the U.S. public, as estimated from the total food supply and commodity flows from production to end uses. Food available for consumption exceeds actual consumption because not all forms of waste or loss can be estimated, such as during preparation and cooking in the home or in food service establishments (14). Therefore, food availability data overstate levels of aggregate and per capita consumption but provide *1*) information about trends over time in fructose availability for consumption and *2*) information about the distribution of sugar types used by industry groups. Implicit in our examination of trends in fructose availability was the assumption that the percentage loss of fructose from the food supply has been constant over time.

We used per capita food availability data compiled by the USDA Economic Research Service (ERS). We presented availability data for sucrose and HFCS separately and grouped all other sweeteners (honey, edible syrups, crystalline fructose, and fructose-only syrups) into 1 category (other) because the total of their relative availability was small (15). For the primary food sources of naturally occurring (N) fructose, we obtained availability data for fruits, vegetables, and flour and cereal products.

Dietary data for estimation of fructose intakes. The 1993 authors calculated the mean DI of fructose using dietary recall data for 30,770 individuals in the 1977–1978 NFCS. The NFCS collected up to 3 d of dietary records per respondent, including 1 interviewer-recorded 24-h dietary recall and 1 or 2 d of self-administered eating records.

For this study, we used NHANES 1999–2004 dietary recalls for 25,165 individuals age 1 y and older (excluding breast-fed infants and pregnant and lactating women). NHANES 1999–2004 interviewers used the 5-step multiple-pass method for estimating dietary intake, which improved accuracy of estimates over the dietary recall approach used in the NFCS (16). We assessed usual DI of fructose using the Iowa State University approach. Usual DI is defined as the long-run average of DI by an individual, or the mean DI net of within-person variance. Because the observed intake distribution includes within-person and between-person variation, this method was developed for adjusting observed intake distributions to remove within-person variation (17–19). These adjustments require 2 d or more of intake data for at least some subjects and can be done using Software for Intake Distribution Estimation (*C-SIDE*) (19).

NHANES 1999–2002 contains a single 24-h recall for each respondent. Beginning in 2003, NHANES conducted a second dietary recall by telephone, 3 to 10 d after the initial dietary interview. The second recall provides data needed to estimate the distributions of usual dietary intakes. We used the 2 recalls from NHANES 2003–2004 to estimate variance components (estimates of within-person variance), which we then used to adjust the single-day intakes for the entire sample of NHANES 1999–2004 following the current method for estimating usual intake (18,20,21) and using the *C-SIDE* software.

Statistical methods. The CDC released the NHANES 1999–2002 with sample weights for the interview sample and the examination sample from the mobile exam unit (MEC) but not a dietary recall sample. We recalibrated the MEC weights, consistent with *What We Eat in America* to account for nonresponse to the dietary recall and to provide proportionate weighting of weekday and weekend recalls (21). NHANES 2003–2004 included dietary recall weights constructed according to the *What We Eat in America* methodology. After combining the 6 y of NHANES 1999–2004, we again recalibrated the dietary recall sample weights to construct 6-y weights, according to the NHANES analytic guidelines (22). We then constructed jackknife weights for use in *C-SIDE* to control for the complex survey design.

After constructing estimates of fructose intake (g/d) at the individual level (described below), we constructed individual measures of fructose intake as a percentage of energy, carbohydrate, and kg body weight. Body weight was measured as part of the NHANES MEC examination. We used reference values of 1 kg body weight for persons with BMI outside the normal range (21). For each of these 4 measures, we estimated mean usual DI and the distribution of usual DI for age and gender groups.

Estimation of fructose intake: added sugar in foods. NHANES and the USDA MyPyramid Equivalents Database (MPED) together provide measures of dietary intake for total sugars and added sugars at the individual level. We show the structure and relevant content of NHANES Individual Food Files (IFF) and MPED IFF and the identifiers that link the databases together (**Supplemental Fig. 1**). After linking the NHANES and MPED files by respondent identifier and food record, we had a single database with measures of total sugar (g) and added sugar (1 teaspoon = 4.196 g). We converted added sugar to grams and calculated grams of N sugar as the difference between total and added sugar. NHANES and MPED do not include measures of types of sweeteners.

The CDC releases the NHANES in 2-y waves (1999–2000, 2001–2002, and 2003–2004). MyPyramid data were available for NHANES 1999–2002 when we began our study, but the USDA had not released the MyPyramid data for 2003–2004. Therefore, to enable use of the 2003–2004 data with its second 24-h recall, we matched foods in NHANES 2003–2004 with MyPyramid records from 1999–2002 to assign added sugar to foods. For the new foods in the NHANES 2003–2004 that did not appear in earlier waves, we estimated the added sugars by matching them with similar foods from the same food groups based on their nutrient content for total sugars, energy, and carbohydrates. The MyPyramid added sugar values were derived using different methods in 1999–2000 and 2001–2002 (23). We used previously documented methods (24) that provided consistency across these 2 sets of values.

Estimation of fructose intake: conversion factors. We used the same methods as the 1993 study (2) and estimated fructose intake by applying conversion factors to measures of added and N sugar in the NHANES IFF (13). Conversion factors for added sugar represent the fructose percentage of added sugar for the food group, based on sugar deliveries to an industry sector such as bakery or confectionery. We used the USDA ERS data on deliveries of amount of sugar and sweeteners for human consumption by type of use to derive conversion factors for added sugar in the dietary survey data (14). USDA ERS ceased publishing these data in complete form in 1992. Data released from 1992 to the most recent in 2002 are incomplete in several industry sectors resulting in an average of <70% of overall industry sector deliveries of sweeteners in the 2002 data. Therefore, we used the last complete data from 1992 to calculate the conversion factors for estimating added fructose consumption by food group.

USDA data provide comparable measures of sweeteners by use for glucose, dextrose, HFCS-42, and HFCS-55. To calculate conversion factors, the total amount of each type of sweetener was multiplied by the sugar content of the sweetener (e.g., sucrose is 100% sugar; HFCS contains 98% sugar) to derive total sugar deliveries. The conversion factors were equal to the percentage of total sugar deliveries from each source: sucrose, HFCS, and other corn sweeteners. An additional conversion factor for fructose was calculated by multiplying the amount of sugars in HFCS by the fructose content of HFCS (HFCS-42 is 42% fructose; HFCS-55 is 55% fructose). Finally, we included estimates for free and bound (one-half the conversion factor for sucrose) fructose in our calculations (2). One difference between our calculations and earlier studies is that earlier studies (2) assumed all HFCS used by the beverage industry was HFCS-55, whereas HFCS deliveries for all other uses were assumed to be 42% fructose. Currently, approximately half of HFCS-42 is used for beverages, whereas industrial use of HFCS-55 includes some foods as well as beverages. Industry sources report that they use HFCS-55 in carbonated soft drinks and HFCS-42 in many fruit-flavored noncarbonated beverages (23). Therefore, we applied different fructose conversion factors to carbonated and noncarbonated beverages.

Conversion factors for added sugar were derived for the 6 categories of use reported in USDA data on deliveries of sugar and sweeteners. To apply the conversion factors to dietary survey data, earlier studies assigned 13 food groups to the 6 food use categories (**Table 1**) (2,13). We used the same 13 food groups, assigning the food group codes to individual food records using the first 1 or 2 digits of the USDA food code. We then aggregated added sugar intakes by person and food group and applied the appropriate conversion factor for food groups to estimate fructose intakes from added sugars.

The main sources of N sugars are fruits (fructose) and milk (lactose). In addition, sucrose occurs naturally in fruits, vegetables, grain, legumes, and nuts. We used the conversion factors for naturally occurring fructose (N fructose) from the earlier studies which denoted the percentage of N sugars by source (sucrose and fructose) and food group, based on analytic data (13). We used the same conversion factors because more recent data were not available. A stepwise summary of our analysis can be found in the Supplemental Material (**Supplemental Table 1**).

TABLE 1 Allocation of 13 USDA food-coding groups to 6 sugar-use categories in applying fructose conversion factors[1]

Use of sugar category	USDA food-coding group
1. Ice cream and dairy products	1. Milk and milk products
2. Bakery and cereal products	2. Grain products
3. Canned, bottled, and frozen foods	3. Legumes and legume products
4. Confectionary and related products	4. Fruit and fruit products
5. Beverages	5. Vegetables and vegetable products
6. All other foods	6. Fats, oils, and salad dressings
	7. Miscellaneous foods
	8. Sugars and sweets
	9. Nonalcoholic beverages
	10. Alcoholic beverages
	11. Meat, poultry, fish, and products
	12. Eggs, egg products, and substitutes
	13. Nuts, seeds, and products

[1] After Glinsmann et al. (13).

Results

Fructose availability in the food supply. Since the earlier report through 1993 (3), the change in per capita availability of total sweeteners (g/d dry weight) increased to a high of 187.9 g/d in 1999 (top line with the composition divided by sucrose, HFCS, and all other sweeteners: honey, edible syrups, crystalline fructose, and fructose-only syrups), then declined gradually to 175.6 g/d in 2003, and remained constant at 176 g/d through 2005 (**Fig. 1 *A***). At the peak of added sweetener availability in 1999 (187.9 g/d), the ratio of percentage sucrose to percentage HFCS was 44:42. Since 1999, total sweetener availability has declined, and the percentage ratio of sucrose to HFCS availability has remained constant. Since 1993, including adjustment for loss, the change in per capita availability of sweeteners has been small, but the composition of sweeteners has changed: total sweetener availability increased by 2.2 g/d, sucrose availability decreased by 0.9 g/d, HFCS availability increased by 4.0 g/d, and the other sweeteners decreased by 1.0 g/d (1). Availability of total sweeteners increased 1%, whereas HFCS availability increased 6%.

Of interest in this study is a comparison of per capita sugar and sweetener availability between the 1977–1978 NFCS study and this NHANES 1999–2004 analysis. From 1978 to 2003, estimated per capita total sweetener availability increased 16.6% (150.8 g/d to 175.9 g/d) with sucrose availability decreasing 32.7% (113.6 g/d to 76.5 g/d), HFCS increasing 60.8% (13.4 to 74.2 g/d), and other sweeteners increasing 6.3% (23.7 g/d to 25.2 g/d). In 1978, the ratio of percentage sucrose to percentage HFCS to percentage other sweeteners was 75:9:16. In 2004, the same percentage ratio was 44:42:14.

Earlier analysis of per capita availability of fresh fruits, fresh vegetables, and flour and cereal products from 1970 to 1988 reported an increased availability of these sources of N fructose over that 18-y period with 20% increase overall (2). From 1988 to 2005 (Fig. 1 *B*), the availability of these food categories has

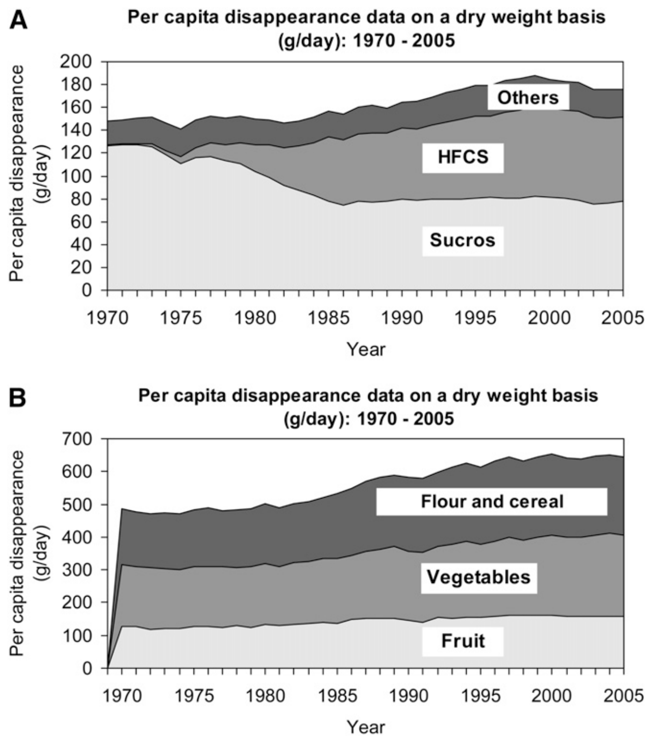

FIGURE 1 Per capita availability (disappearance) of sweeteners on a dry-weight basis in the United States, 1970–2005 (*A*) and of fresh fruits and fresh vegetables measured at retail weight and flour and cereal products (*B*) based on data from the USDA (14). Availability data for sucrose and HFCS are presented separately, and all other sweeteners (honey, edible syrups, crystalline fructose, and fructose-only syrups) are grouped into the category (other) because the total of their relative availability is small.

fluctuated annually with an overall increase in availability of 10%. From 1978 to 2004, availability of fresh fruits increased 23.3% (128.9 g/d to 158.9 g/d), fresh vegetable availability increased 41% (178.2 g/d to 251.5 g/d) and that of flour/cereal products increased 34.7% (177.3 g/d to 238.9 g/d).

Estimates of fructose intake. To enhance comparisons with the 1978 NFCS data, we have presented the NHANES 1999–2004 intake data in tables and figures similar to those of the earlier work (2). Thus, we presented the estimates of usual mean fructose intake, standard error, 90th and 95th percentile of added, N, and total fructose intake based on the NHANES 1999–2004 (**Table 2**) for the same gender and age groups in the 1980 *Recommended Dietary Allowances* (25), as in the previously published study (2). Young men in age groups 15–18 y and 19–22 y had the highest estimated mean intake of total fructose: 75 g/d. Among women, the 15–18 y and 19–22 y age groups had the highest total fructose intake: 55 g/d and 61 g/d, respectively. Women overall had estimated fructose intakes that were lower than those of men among all age groups: 48.6 g/d vs. 62.8 g/d (data not shown).

Total and added fructose, as a percentage of energy, presented as 3-y moving averages of estimates by year of age for both genders combined, had the same pattern and increased from 1 y (9%; 5.8%) to 15–18 y (11%; 9.9%) and decreased with increasing age (**Fig. 2** *A*) (3). Estimated mean total fructose as percentage of energy plateaus after age 60 y at 7.6%. However, estimated intake of added fructose as percentage of energy decreased more rapidly than total fructose among persons >55 y. N fructose intake as percentage of energy decreased from age 1 to 8 y and remained relatively constant at under 2% of energy until age >55 y, when it increased to over 2%. The estimated total energy intake across the age groups was 1817 kcal/d (4) in the 1977–1978 NFCS and 2148 kcal/d in the 1999–2004 NHANES, or an 18% increase in daily energy intake between the surveys (**Supplemental Table 2**).

Mean fructose intake as a percentage of carbohydrate intake (Fig. 2 *B*) followed a similar age-dependent pattern as seen for fructose as percentage of energy intake. The peak in total and added fructose intake as a percentage of carbohydrates similarly was seen in young adults age 15 to 18 y (19.9 and 17.5%) with a steady decrease in total and added fructose intake as a percentage of carbohydrates with increasing age. The drop in fructose intake as a percentage of carbohydrate intake reflected an even more dramatic ~41% increase in carbohydrate intake from an estimated mean total of 193 g/d in the 1977–1978 survey to 272 g/d in the 1999–2004 survey (**Supplemental Table 3**).

For daily fructose intake by body weight for both genders combined, N fructose intake decreased with increasing age until ~11 y and then flattened at 0.1 g/kg body wt (Fig. 2 *C*)**.** Total and added fructose intake similarly decreased until age 11 y and then continued to decrease more gradually through age 77 y. Added fructose paralleled total fructose with age, and a slight increase in both occurred at 15 to 18 y (~1.1 $g \cdot kg^{-1} \cdot d^{-1}$ and ~1.0 $g \cdot kg^{-1} \cdot d^{-1}$, respectively) (**Supplemental Table 4**).

Dietary sources of sweeteners. Across all gender and age groups, the highest mean percentage of added fructose intake was from nonalcoholic beverages (54.3%) and grain products (G) (20.3%) (**Table 3**). For N fructose, the predominant dietary sources were fruits and fruit products (FR) (72.5%). For total fructose, nonalcoholic beverages (46%) and G (17.3%) were the predominant dietary sources, overall. However, for children 1 to 3 y the predominant source of total fructose was FR (37.6%), and for children 4 to 6 y, nonalcoholic beverages (34.0%) predominated, followed by FR (21.2%). These differences for young children in the FR category undoubtedly reflected a higher intake of fruit juices and juice drinks in these age ranges. The combined food groups of FR and G exceeded the percentage for total fructose from nonalcoholic beverages for men (38.9 vs. 32.3%) and women (44.5 vs. 27.8%) >51 y. The highest percentage of total dietary fructose from nonalcoholic beverages was reported by young men ages 15 to 18 y and 19 to 22 y (60.7 and 65.6%) and young women ages 15 to18 y and 19 to 22 y (57.1 and 56.4%).

Discussion

This article presents an update and extension from 1993 through 2005 of previously published (3) USDA data for the availability of sweeteners and food sources of N fructose. We provided new estimates of usual DI of fructose based on NHANES 1999–2004 for comparison with previously published estimates based on the 1977–1978 NFCS. We found that total estimated mean usual DI of fructose across all gender/age groups was 49 g/d compared with the earlier reported NFCS 1977–1978 value of 37 g/d (2). Fructose intake increased in all gender and age groups since 1978.

This study gave an overview of the trends in availability of added sweeteners and the major food sources of N fructose that can contribute to intake in the United States. The repeated tripling of availability of HFCS from 4 to 12 to 36% of total sweeteners across the 10 y from 1975 to 1980 to 1985 (56.1 g/d),

TABLE 2 Estimated mean and 90th and 95th percentile usual fructose intakes of the U.S. population (≥1 y old) by gender and age groups (NHANES, 1999–2004)[1–4]

Gender/age group	size[5]	Mean Added	Mean Naturally occurring	Mean Total[6]	90th Percentile Added	90th Percentile Naturally occurring	90th Percentile Total[7]	95th Percentile Added	95th Percentile Naturally occurring	95th Percentile Total[7]
Both sexes	*n*		*g/d*			*g/d*			*g/d*	
1–3 y	2,087	22 ± 0.9	12 ± 0.5	34 ± 1.0	40 ± 2.0	22 ± 0.9	54 ± 1.7	47 ± 2.4	27 ± 1.1	62 ± 2.0
4–6 y	1,458	34 ± 1.3	9 ± 0.5	43 ± 1.3	50 ± 2.0	17 ± 0.8	61 ± 2.1	56 ± 2.3	20 ± 1.0	68 ± 2.3
7–10 y	2,001	44 ± 2.1	7 ± 0.5	51 ± 2.1	66 ± 3.7	13 ± 1.0	71 ± 3.4	74 ± 4.4	15 ± 1.2	79 ± 4.0
Males										
11–14 y	1,504	53 ± 2.5	7 ± 0.5	60 ± 2.3	78 ± 4.2	13 ± 0.9	87 ± 4.4	87 ± 5.2	16 ± 1.2	97 ± 9.2
15–18 y	1,704	68 ± 2.4	8 ± 0.8	75 ± 2.7	102 ± 4.3	15 ± 2.1	109 ± 4.5	116 ± 5.1	19 ± 2.2	121 ± 5.0
19–22 y	746	67 ± 4.5	8 ± 1.1	75 ± 4.2	107 ± 9.2	15 ± 2.3	117 ± 8.9	122 ± 12.6	19 ± 2.9	134 ± 12.2
23–50 y	2,925	54 ± 1.7	8 ± 0.6	63 ± 1.8	93 ± 3.4	17 ± 1.3	103 ± 3.1	108 ± 3.4	21 ± 1.8	118 ± 3.9
51 + y	3,076	32 ± 1.3	9 ± 0.4	41 ± 1.5	57 ± 2.8	18 ± 0.8	67 ± 3.0	69 ± 4.1	22 ± 1.0	79 ± 4.4
Females										
11–14 y	1,639	43 ± 1.9	7 ± 0.4	50 ± 2.0	63 ± 2.7	12 ± 0.7	69 ± 2.6	71 ± 3.1	14 ± 0.7	76 ± 2.9
15–18 y	1,485	48 ± 2.2	7 ± 0.4	55 ± 2.3	71 ± 3.8	15 ± 1.1	80 ± 3.6	80 ± 4.5	18 ± 1.4	89 ± 4.4
19–22 y	609	54 ± 3.3	7 ± 0.8	61 ± 3.4	90 ± 6.1	14 ± 1.7	100 ± 6.0	105 ± 7.5	17 ± 2.1	116 ± 7.2
23–50 y	2,769	39 ± 1.4	7 ± 0.4	45 ± 1.2	70 ± 2.8	13 ± 0.8	76 ± 2.2	84 ± 4.8	16 ± 0.8	90 ± 3.2
51 + y	3,167	24 ± 0.9	8 ± 0.3	32 ± 0.8	42 ± 1.5	16 ± 0.6	52 ± 1.4	50 ± 1.9	19 ± 0.8	60 ± 1.7
Total	25,170	41 ± 0.8	8 ± 0.2	49 ± 1.0	68 ± 1.4	16 ± 0.1	75 ± 2.1	78 ± 4.0	20 ± 1.0	87 ± 4.0

[1] Values are means ± SE.
[2] Pregnant and lactating women and breast-fed infants excluded.
[3] The 13 gender and age groups presented here were used by the comparison study by Park and Yetley (2) and are the age groups used in the 9th edition of the *Recommended Dietary Allowances* (25) with the exception that we did not include children younger than 1 year of age. This same information presented for the current Dietary Reference Intake gender/age groups (26) is in **Supplemental Table 5**.
[4] Source: NHANES 1999–2004 self-reported 24-h recall data from 2 recalls combined. Usual intake was estimated using *C-SIDE* (17–19).
[5] Unweighted sample size.
[6] Sums of added and N fructose may not agree with totals presented because of rounding.
[7] Data for the 90th and 95th percentiles and SE for each gender/age group are presented for added, naturally occurring, and total fructose, respectively; therefore, the 90th and 95th percentiles of added and N fructose in each column will not sum to equal the total.

which represented a change in the sucrose:HFCS composition of sweetener availability to 50:36% (2,13) has not continued. However, between the 1977–1978 NFCS and this NHANES 1999–2004 study, per capita availability of HFCS increased 60.8%. From 1985 to 1993, HFCS increased to 67.7 g/d; then from 1994 to 2005 HFCS availability increased to 73.4 g/d per capita. Sucrose, HFCS, and "other" sweeteners accounted for 44, 42, and 14%, respectively, of total sweeteners in 1999, and these percentages have remained constant since then.

The availability of the primary dietary sources of N fructose has increased more slowly since earlier reports (2). Between 1978 and 2004, per capita availability of fresh fruits increased 23.3%, fresh vegetable availability increased 41%, and flour/cereal product availability increased 34.7%. The availability of these sources of N fructose increased ~10% in the last 17 y (since 1988) after increasing 20% in the previous 18 y (2).

Since the 1977–1978 NFCS data were collected, improvements have been made in data collection and analysis such as the use of interviewer-guided 24-h dietary recall with the research-validated USDA 5-step multiple-pass method (16), a second recall by telephone, MEC measured body height and weight, and estimates of usual intake through the method developed at Iowa State University (17–19). We recognized that the differences in estimated fructose intake from the 1977–1978 NFCS and 1999–2004 NHANES data may be due in part to these and other methodological changes, which we cannot assess and must be viewed as limitations to the study. We therefore presented the following comparisons between the 2 studies with these differences in mind.

Estimated mean DI of fructose based on national surveillance data had increased in all gender and age groups from 1978 to 2004, consistent with trends in fructose availability. In this analysis, estimated mean DI of total fructose increased from as little as 3 g/d among women >51 y to 28 g/d among men 1922 y. Added fructose intake increased in all gender and age groups (mean of 6 to 33 g/d per gender and age group). In contrast, N fructose intake decreased 3 to 7 g/d for the various gender and age groups with the exception of children 1–3 y, among whom there was no change. The largest increase in fructose intake was among men and women 19–22 y, who evidenced a mean increase in intake of added fructose of 33 g/d and 30 g/d and a mean increase in total fructose of 28 and 26 g/d, respectively. The 1977–1978 analysis (2) found that males 15 to18 y old and females 11 to14 y old had the highest estimated intake of fructose. NHANES 1999–2004 estimates indicated that males 15 to18 y old and 19 to 22 y old took in equivalent estimated highest levels of total fructose (75 g/d), but among females, the age group with the highest intake shifted to 19–22 y.

The overall estimated mean total fructose intake as a percentage of energy also increased, from 8.1% in 1978 to 9.1% in 2004. The increase of total fructose intake as a percentage of energy is not as striking as the increase in grams per day because of the increase of 18% in overall total energy intake. Based on the NHANES 1999–2004 estimates, as a percentage of energy intake, young women 19–22 y old have the highest mean intake of added (10.2%) and total fructose (11.6%).

The overall estimated mean total fructose intake when expressed as a percentage of carbohydrate intake declined in the same period, from 18.6% in 1978 to 17.1% in 2004. The drop in fructose intake as a percentage of carbohydrate intake reflected the ~41% overall estimated increase in carbohydrate intake in this time period.

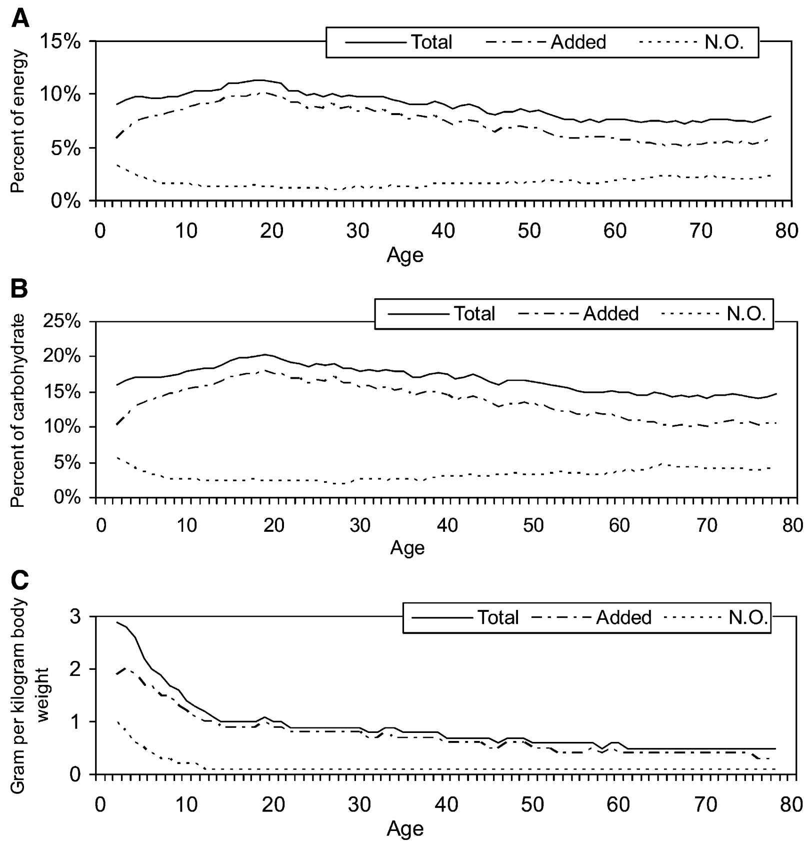

FIGURE 2 Estimated mean usual added, naturally occurring, and total fructose intake as percentage of energy intake (*A*), as percentage of carbohydrate intake (*B*), and as grams per kilogram of measured body weight (*C*) of the U.S. population (≥1 y old) by age in years, excluding pregnant and lactating women and breast-fed infants (NHANES, 1999–2004).

The 1977–1978 NFCS analysis (2) did not include the numerical results for fructose intake for body weight. These authors commented that the gender differences "observed for the DI (daily intake) disappeared when the DI was expressed per kilogram body weight" (p. 743S). The NHANES 1999–2004 data similarly showed an equalization in the gender differences in mean fructose intake by age group when body weight was the denominator. However, the difference between self-reported body weight in the 1977–1978 NFCS analysis and measured body weight in the NHANES 1999–2004 may have affected this comparison.

In the analysis of the 1977–1978 NFCS data, nonalcoholic beverages accounted for the largest percentage of total average DI of added and total fructose for all age groups with the exception of total fructose for children 1 to 3 y of age where FR were the main source. G in 1978 were the second most frequent source of added fructose, and FR were the main source of N fructose with G also predominant. The 1999–2004 data exhibited the same patterns with the exception that where G were contributing from 14–30% of the N fructose in the 1977–1978 NFCS analysis, the G group contributed only 1–4% of the N fructose in the present analysis. Across all gender/age groups, the total percentage DI of N fructose in 1977–1978 NFCS was 53% FR, 23% G, and 15% vegetables and vegetable products (V) compared with 73% FR, 3% G, and 11% V in this 1999–2004 NHANES analysis.

This study, similar to the earlier 1977–1978 analysis (2), is limited in that the fructose content of foods required estimation. The USDA has provided a specialty database that addressed added sugars and, separately, fructose intake in common foods (27). It would be helpful, with the current national prevalence of overweight and obesity (28,29), to include the composition of added sugars or at least to identify the sucrose, fructose, and other sweetener composition of added sugars in the full USDA Food and Nutrient Database for Dietary Studies.

In recent years, the composition of added sweeteners has not continued the rapid increases seen in the 10 y from 1975 to 1985. Instead, the data through 2005 indicated that the availability of added sweeteners matches levels seen in 1994, and the HFCS percentage of the total has remained relatively constant at 42%. However, between 1978 and 2004, the per capita availability of HFCS increased 60.8%. Comparison of the 1977–1978 NFCS analysis with our analyses of NHANES 1999–2004 indicated that, over the interval, mean individual intakes of total fructose increased by ~32%. This change in fructose intake coincided with an 18% increase in daily estimated energy intake and a 41% increase in daily estimated carbohydrate intake. Nonalcoholic beverages and G were the predominant sources of added fructose in the diet in both 1977–1978 and 1999–2004. G and vegetable products contributed less to N fructose intake in the NHANES 1999–2004 analyses compared with the 1977–1978 NFCS, whereas FR contributed more to N fructose intake in the later study. However, of the 3 product groups contributing to N fructose intakes, per capita availability of fresh vegetables had the largest increase from 1978 to 2004 of 41% compared with 34.7% for flour/cereal products, and 23.3% for fruits.

Sugar consumption has come under increased scrutiny as rates of overweight and obesity in the United States have increased. Factors that can lead to overweight in America are complex. As 1 example, research has shown that the availability of food diversity has increased food intake (30). In the United States, the diversity of foods in the marketplace continues to expand, with an average of >12,000 new grocery items introduced annually (31). The number of different food items purchased by households has increased as food expenditures

TABLE 3 Percentage of DI of food sources for total, added, and N fructose of the U.S. population (≥1 y old) by gender and age groups (NHANES, 1999–2004)[1–4]

	Both sexes			Male					Female					Mean
	1–3 y	4–6 y	7–10 y	11–14 y	15–18 y	19–22 y	23–50 y	≥51 y	11–14 y	15–18 y	19–22 y	23–50 y	≥51 y	total
Added fructose							*% of DI*							
Milk and milk products	14.2	15.6	12.0	8.6	5.6	4.1	6.0	11.6	8.4	5.5	7.5	8.7	11.2	8.6
Grain products	26.2	22.6	23.5	20.4	15.9	11.1	16.9	25.7	19.6	16.0	13.7	19.8	31.8	20.3
Sugars and sweets	15.6	15.1	16.2	12.2	7.9	8.3	9.7	14.3	14.0	11.1	12.6	12.6	14.5	12.1
Nonalcoholic beverages	38.7	42.7	45.6	56.2	67.5	72.9	63.2	40.6	55.5	64.6	63.2	53.6	35.5	54.3
Naturally occurring fructose														
Grain products	1.2	2.4	3.9	4.1	4.5	3.5	3.8	3.4	4.2	3.5	3.0	3.6	3.0	3.4
Fruit and fruit products	91.2	86.0	79.1	79.6	71.9	74.7	65.0	71.8	74.6	74.2	62.7	66.4	74.8	72.5
Vegetables and veg. products	2.8	4.4	7.2	6.0	9.3	10.1	11.6	13.9	8.6	8.5	11.5	12.3	13.1	10.6
Sugars and sweets	0.6	0.8	1.8	1.2	0.7	1.8	1.5	1.5	1.8	1.6	3.4	2.1	2.2	1.7
Nonalcoholic beverages	3.7	5.7	6.7	7.7	10.8	6.1	6.1	4.2	9.7	9.4	15.4	9.3	4.2	6.6
Alcoholic beverages	0.0	0.0	0.0	0.0	1.5	1.9	10.1	3.6	0.0	1.4	2.3	4.9	1.4	3.8
Total fructose														
Milk and milk products	8.6	11.9	10.4	7.4	4.9	3.6	5.1	9.0	7.2	4.7	6.4	7.2	8.5	7.1
Grain products	16.4	17.8	20.9	18.2	14.6	10.2	15.0	20.6	17.4	14.3	12.2	17.0	24.7	17.3
Fruit and fruit products	37.6	21.2	11.2	11.2	8.8	8.4	9.4	18.3	11.0	10.6	9.1	12.1	19.8	13.4
Vegetables and veg. products	1.7	2.0	1.7	1.6	2.0	2.1	2.5	4.3	1.9	1.8	2.2	2.8	4.0	2.7
Sugars and sweets	9.7	11.7	14.3	10.7	7.0	7.6	8.5	11.4	12.3	9.8	11.3	10.8	11.5	10.3
Nonalcoholic beverages	24.9	34.0	40.4	49.7	60.7	65.6	55.1	32.3	49.0	57.1	56.4	46.1	27.8	46.0

[1] Table shows the percentage of fructose intake contributed by each food group, for each category of fructose. Food groups were defined according to the first 1 or 2 digits of the USDA food code. Twelve USDA food groups were examined. Food groups listed under each category of fructose accounted for at least 3% of fructose intake for at least 1 age group.

[2] The analysis excluded pregnant and lactating women and infants.

[3] The 13 gender and age groups presented here were used by the comparison study (2) and are the age groups used in the 9th edition of the *Recommended Dietary Allowances* (16) with the exception that we did not include children less than 1 year of age. This same information presented for the Dietary Reference Intake gender/age groups (26) is in **Supplemental Table 6**.

[4] Source: NHANES 1999–2004 24-h dietary recall. Estimates are based on a single dietary recall per person.

have increased (31,32), with availability of increased income spent on food to please tastes, not to meet nutritional needs (33). Sweetener consumption is only 1 part of the complex dietary component of trends in overweight.

This article examines trends in fructose availability in the food supply and fructose intakes by gender and age group based on NHANES 1999–2004. The 2005 *Dietary Guidelines for Americans* (34) and the *MyPyramid Food Guidance System* recommend limiting "discretionary calories." USDA introduced a measure of discretionary energy consumption, which includes energy from solid fats, alcoholic beverages, and added sugars (35), and found that average consumption ranged from 30 to 42% of energy across gender and age groups. To change food intake patterns in the United States, policymakers require an understanding of the sources of discretionary energy in American diets. We think the analysis of fructose intake in this article can provide insight into the types and sources of sugar consumption in the United States to help understand some sources of discretionary energy.

Other articles in this supplement include (15, 36–44).

Acknowledgments

We thank Fran Seligson, Ph.D., for her helpful suggestions during all stages of the project; Lauren Olsho, Ph.D., and Alan White, Ph.D., for help with the final computations; Mary Brandt, Ph.D., for her comments and research; and Janice Abbas and Hao Nguyen for manuscript preparation. We appreciate the organization, content knowledge, and management that Marie Latulippe of ILSI, North America brought to the project.

Literature Cited

1. Mintz SW. Sweetness and power: the place of sugar in modern history. New York: Viking Penguin; 1985.
2. Park YK, Yetley EA. Intake and food sources of fructose in the United States. Am J Clin Nutr. 1993;58: S737–47.
3. Glinsmann WH, Park YK. Perspective on the 1986 Food and Drug Administration assessment of the safety of carbohydrate sweeteners: uniform definitions and recommendations for future assessments. Am J Clin Nutr. 1995;62: S161–8.
4. Bray GA, Nielsen SJ, Popkin BM. Consumption of high-fructose corn syrup in beverages may play a role in the epidemic of obesity. Am J Clin Nutr. 2004;79:537–43.
5. Havel PJ. Dietary fructose: implications for dysregulation of energy homeostasis and lipid/carbohydrate metabolism. Nutr Rev. 2005;63:133–57.
6. Schulze MB, Manson JE, Ludwig DS, Colditz GA, Stampfer MJ, Willett W, Hu FB. Sugar-sweetened beverages, weight gain, and incidence of Type 2 diabetes in young and middle-aged women. JAMA. 2004;292:927–34.
7. Mrdjenovic G, Levitsky D. Nutritional and energetic consequences of sweetened drink consumption in 6- to 13-year-old children. J Pediatr. 2003;142:604–10.
8. James J, Kerr D. Prevention of childhood obesity by reducing soft drinks. Int J Obes (Lond). 2005;29: Suppl 2:S54–7.
9. Ludwig DS, Peterson K, Gortmaker S. Relation between consumption of sugar-sweetened drinks and childhood obesity: a prospective, observational analysis. Lancet. 2001;357:505–8.
10. Newby PB, Peterson K, Berkey C, Leppert J, Willett W, Colditz GA. Beverage consumption is not associated with changes in weight and body mass index among low-income preschool children in North Dakota. J Am Diet Assoc. 2004;104:1086–94.
11. Berkey CS, Rockett H, Field A, Gillman M, Colditz GA. Sugar-added beverages and adolescent weight change. Obes Res. 2004;12:778–88.

12. Rajeshwari R, Yang S, Nicklas TA, Berenson GS. Secular trends in children's sweetened-beverage consumption (1973–1994): the Bogalusa Heart Study. J Am Diet Assoc. 2005;105:208–14.
13. Glinsmann WH, Irausquin H, Park YK. Evaluation of health aspects of sugars contained in carbohydrate sweeteners: Report of Sugars Task Force. J Nutr. 1986;116: Suppl 11:S1–216.
14. Sugar and sweeteners briefing room. Sugar and sweeteners (database on the Internet): USDA Economic Research Service. 2008 [cited 2007 Nov]. Available from: http://www.ers.usda.gov/Briefing/Sugar/Data.htm.
15. White JS. Misconceptions about high-fructose corn syrup: is it uniquely responsible for obesity, reactive dicarbonyl compounds, and advanced glycation endproducts? J Nutr. 2009;139:1219S–27S.
16. Conway JM, Ingwersen L, Moshfegh AJ. Accuracy of dietary recall using the USDA five-step multiple pass method in men: an observational validation study. J Am Diet Assoc. 2004;104:595–603.
17. Nusser SM, Carriquiry AL, Dodd KW, Fuller WA. A semi-parametric transformation approach to estimating usual nutrient intake distributions. J Am Stat Assoc. 1996;91:1440–9.
18. Carriquiry AL, Camano-Garcia G. Evaluation of dietary intake data using the tolerable upper intake levels. J Nutr. 2006;136:507S–13S.
19. Carriquiry AL. Estimation of usual intake distributions of nutrients and foods. J Nutr. 2003;133:601S–8S.
20. Dwyer J, Picciano MF, Raiten DJ. Estimation of usual intakes: What We Eat in America-NHANES. J Nutr. 2003;133:609S–23S.
21. Moshfegh A, Goldman J, Cleveland L. What we eat in America, NHANES 2001–2002: Usual nutrient intakes from food compared to dietary reference intakes Washington, DC: USDA, Agricultural Research Service; 2005.
22. National Center for Health Statistics. National Health and Nutrition Examination Survey Analytic Guidelines. NCHS; 2004 [cited 2004 Oct 25]. Available from: http://www.cdc.gov/nchs/about/major/nhanes/currentnhanes.htm#Interviewer
23. hfcsfacts.com [homepage on the Internet]. Washington DC: High fructose corn syrup facts; 2008 [updated 2008; cited 2008 June]. Available from: http://www.hfcsfacts.com/.
24. Cole N, Fox MK. Diet quality of Americans by Food Stamp program participation status: data from the National Health and Nutrition Examination Survey, 1999–2004. Cambridge, MA: Food and Nutrition Service; 2008. Report No.: FSP-08-NH. Contract No.: 43–3198–4-3810. Sponsored by the United States Department of Agriculture.
25. National Research Council. Recommended Dietary Allowances, 9th ed. Washington, DC: National Academy Press; 1980.
26. Institute of Medicine. Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride. Washington, DC: National Academy Press; 1997.
27. Nutrient Data Laboratory, Beltsville Agricultural Research Center, Beltsville Human Nutrition Research Center. USDA database for the added sugars content of selected foods, release 1. Beltsville, MD: Agricultural Research Service, USDA; 2006.
28. Ogden CL, Carroll MD, McDowell MA, Flegal KM. Obesity among adults in the United States—no statistically significant change since 2003–2004. NCHS data brief no. 1. Hyattsville (MD): 2007. Sponsored by the National Center for Health Statistics.
29. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. JAMA. 2006;295:1549–55.
30. Rolls BJ, Barnett RA. Volumetrics: feel full on fewer calories. New York: Harper Collins; 2000.
31. Jekanowski MD, Binkley JK. Food purchase diversity across U.S. markets. Agribusiness. 2000;16:417–33.
32. Lee J, Brown MG. Consumer demand for food diversity. South J Agric Econ. 1989;21:47–53.
33. Silberberg E. Nutrition and demand for tastes. J Polit Econ. 1985;93:881–900.
34. U.S. Department of Health and Human Services and U.S. Department of Agriculture. Dietary Guidelines for Americans, 2005. 6th Edition, Washington, DC: U.S. Government Printing Office; 2005.
35. Basiotis P, Guenther PM, Lino M, Britten P. Americans consume too many calories from solid fat, alcohol, and added sugar. Nutrition Insight, 33. Alexandria, VA: Center for Nutrition Policy and Promotion, USDA; 2006.
36. Jones JM. Dietary sweeteners containing fructose: overview of a workshop on the state of the science. J Nutr. 2009;139:1210S–3S.
37. Borra ST, Bouchoux A. Effects of science and the media on consumer perceptions about dietary sugars. J Nutr. 2009;139:1214S–8S.
38. Stanhope KL, Havel PJ. Fructose consumption: considerations for future research on its effects on adipose distribution, lipid metabolism, and insulin sensitivity in humans. J Nutr. 2009;139:1236S–41S.
39. Angelopoulos TJ, Lowndes J, Zukley L, Melanson KJ, Nguyen V, Huffman A, Rippe JM. The effect of high-fructose corn syrup consumption on triglycerides and uric acid. J Nutr. 2009;139:1242S–5S.
40. Livesey G. Fructose ingestion: dose-dependent responses in health research. J Nutr. 2009;139:1246S–52S.
41. Moran TH. Fructose and satiety. J Nutr. 2009;139:1253S–6S.
42. Schaefer EJ, Gleason JA, Dansinger ML. Dietary fructose and glucose differentially affect lipid and glucose homeostasis. J Nutr. 2009;139:1257S–62S.
43. John P. Bantle. Dietary fructose and metabolic syndrome and diabetes. J Nutr. 2009;139:1263S–8S.
44. Murphy SP. The state of the science on dietary sweeteners containing fructose: summary and issues to be resolved. J Nutr. 2009;139:1269S–70S.