Sugar Content of Popular Sweetened Beverages Based on Objective Laboratory Analysis: Focus on Fructose Content

Emily E. Ventura[1], Jaimie N. Davis[1] and Michael I. Goran[1,2]

The consumption of fructose, largely in the form of high fructose corn syrup (HFCS), has risen over the past several decades and is thought to contribute negatively to metabolic health. However, the fructose content of foods and beverages produced with HFCS is not disclosed and estimates of fructose content are based on the common assumption that the HFCS used contains 55% fructose. The objective of this study was to conduct an objective laboratory analysis of the sugar content and composition in popular sugar-sweetened beverages with a particular focus on fructose content. Twenty-three sugar-sweetened beverages along with four standard solutions were analyzed for sugar profiles using high-performance liquid chromatography (HPLC) in an independent, certified laboratory. Total sugar content was calculated as well as percent fructose in the beverages that use HFCS as the sole source of fructose. Results showed that the total sugar content of the beverages ranged from 85 to 128% of what was listed on the food label. The mean fructose content in the HFCS used was 59% (range 47–65%) and several major brands appear to be produced with HFCS that is 65% fructose. Finally, the sugar profile analyses detected forms of sugar that were inconsistent with what was listed on the food labels. This analysis revealed significant deviations in sugar amount and composition relative to disclosures from producers. In addition, the tendency for use of HFCS that is higher in fructose could be contributing to higher fructose consumption than would otherwise be assumed.

Obesity (2010) doi:10.1038/oby.2010.255

INTRODUCTION

Sugar-sweetened beverages have been shown to contribute to weight gain in both adults and youth (1–5) and are associated with chronic health consequences including risk for obesity, diabetes, cardiovascular disease, and fatty liver disease (6–10). Per capita caloric intake from sugar-sweetened beverages went from 50 calories in 1965 to over 200 calories in 2002 (11). Soft drinks in the United States, as well as some other popular sugar-sweetened beverages, are sweetened primarily with high fructose corn syrup (HFCS), and it is estimated that Americans ≥ age 2 years ingest at least 132 calories per day from HFCS (5). The consumption of total fructose increased by nearly 30% between 1970 and 2000, largely due to the increased use of HFCS (5). Even when beverages are not sweetened with HFCS and instead contain cane sugar or crystalline fructose, which are often viewed by the public as healthier, more natural alternatives, the overall total sugar content and the fructose content of the beverages are still high and still of concern. In addition to the concerns over the increased caloric intake from increased sugar consumption, there is also an additive metabolic risk associated with high consumption of fructose in particular (12). The consumption of high amounts of fructose has been found to be particularly associated with negative health outcomes (13) such as insulin resistance, triglyceride deposition in the liver (14), and kidney stones (15–18).

High fructose corn syrup can be produced in different formulations, and according to the Corn Refiners Association, HFCS is "either 42 percent or 55 percent fructose" (19) combined with the remaining percentage of glucose, although HFCS with higher fructose content can be produced (20,21). Although food labels are required to provide total grams of sugar in a beverage, complete information regarding sugar composition, i.e., fructose vs. glucose, is not required and not disclosed on the label. Even when the ingredient list specifies "high fructose corn syrup," the actual fructose content of the syrup is not known, as beverage manufacturers do not specify which formulation of HFCS they use. However, there may be a preference for the use of higher percentages of fructose considering that fructose tastes sweeter than glucose. Due to the lack of knowledge of actual fructose content in foods, researchers conducting detailed dietary analyses examining fructose consumption rely on approximations and assumptions of the

[1]Department of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, California, USA; [2]Department of Physiology and Biophysics, Keck School of Medicine, University of Southern California, Los Angeles, California, USA. Correspondence: Michael I. Goran (goran@usc.edu)

Received 23 March 2010; accepted 13 September 2010; advance online publication 14 October 2010. doi:10.1038/oby.2010.255

specifics of HFCS used in food production. Typically these calculations assume that the ratio of fructose:glucose in the HFCS used in food production is 55:45. The objective of the current report was to conduct an objective laboratory analysis of popular sugar-sweetened beverages in order to examine the validity of this assumption and gain more objective data on the sugar composition in popular sweetened beverages, with a particular focus on fructose.

METHODS AND PROCEDURES

Samples of sweetened beverages

Twenty-three samples of popular sugar-sweetened beverages were purchased in East Los Angeles, California. Beverages were selected based on the frequency of consumption by children participating in our past research studies in Los Angeles as well as based on National popularity. All of the samples were domestically produced with the exception of the Mexican Coca-Cola, which is readily available for purchase in East Los Angeles and was selected due to its popularity. The majority of the samples were purchased in cans and bottles, and in addition, six samples of fountain drinks were obtained from local fast food restaurants for use in comparisons to the canned/bottled drinks to explore within-brand variation for Coca-Cola, Sprite, and Pepsi. For the fountain drink samples, beverages were ordered without ice and were purchased the same afternoon in which they were shipped to the laboratory. Four standard solutions were created for simultaneous laboratory testing. These solutions were prepared in the range of sugar content roughly equivalent to most sweetened beverages as follows: pure fructose (10 g/100 ml), pure glucose (10 g/100 ml), pure sucrose (10 g/100 ml), and a 50:50 mixture of fructose and glucose (5 g/100 ml for each sugar). Samples plus standard solutions were transferred to airtight containers and sent overnight from Los Angeles to Krueger Food Laboratories in Billerica, MA, and were kept chilled during shipping. The laboratory was blinded to the source of all samples and standards.

Sugar assays

Samples were analyzed for sugar profiles using high-performance liquid chromatography (HPLC) in an independent certified laboratory (Krueger Food Laboratories, Billerica, MA). The HPLC method assesses free fructose, free glucose, sucrose, maltose, and lactose content in grams per 100 ml (22).

Only the results from the fructose, glucose, and sucrose were used for this report as none of the beverages tested contained detectable amounts of maltose or lactose. Each of the beverage samples was tested once and each of the standard solutions were tested three times on three separate days in order to assess the accuracy of the assay.

Statistics

To assess the reliability of the assays, we calculated the coefficient of variation for the standard solutions. Using the results from the laboratory for the beverage samples, we calculated total sugar content in grams per 100 ml by summing the fructose, glucose, and sucrose results. The total sugar content as assessed by the laboratory was compared to the total sugar content reported on the nutrition label or the nutrition facts published online (in the case of the fountain drinks from fast food restaurants). Finally, for the drinks in which the only source of fructose was HFCS, we calculated the fructose-to-glucose ratio using the laboratory results in order to approximate the formulation of the HFCS used.

RESULTS

Analysis of standard solutions

Table 1 shows the results of the triplicate assays for the standard solutions that were prepared and sent to the laboratory for analysis. The mean fructose detected for the 10 g/100 ml standard solution was 9.9 g/100 ml with a coefficient of variation of 2.6%. The mean glucose detected for the 10 g/100 ml standard solution was 9.8 g/100 ml with a coefficient of variation of 2.7%. The mean sucrose detected for the 10 g/100 ml solution was 9.0 g/100 ml with a coefficient of variance of 8.7%. For the 50:50 standard mixture of free fructose (5.0 g/100 ml) and glucose (5.0 g/100 ml), an average of 5.0 g/100 ml was detected for fructose with a coefficient of variance of 4.2%, and 5.1 g/100 ml was detected for glucose with a coefficient of variance of 3.9%. For the fructose and glucose standards, no sucrose was detected. However, for the sucrose assays, a small amount of fructose was detected but no glucose. The average fructose detected in the 10 g/100 ml sucrose standard was 0.26 g/100 ml, suggesting the potential for a small amount of false positive fructose detection in samples containing sucrose. This result could also be due to an actual trace amount of fructose being present in the control sample.

Total sugar content of popular sweetened beverages

As shown in Figure 1, the total sugar content of the beverages, as assessed by the laboratory, ranged from 85 to 128% of what was listed on the food label or nutrition facts. The bottled samples of Coke, Sprite, and Pepsi tested at 95 to 100% of what was listed on the label. The Dr. Pepper and Mountain Dew samples tested lower than what was listed on the label, with laboratory results of 87% and 92%, respectively, of the listed total sugar content. In the case of the fountain drinks, all of the samples tested higher for total sugar content than the nutrition facts published on the company websites, with actual sugar contents of 101–128% of the listed information. For example, the two fountain samples of Coca-Cola both tested at 38 g of sugar per 12 fluid ounce (FO) compared to publicly

Table 1 Laboratory results from high-performance liquid chromatography analysis of standard sugar solutions

	Standard sugar assayed				
	Fructose standard (10 g/100 ml)	Glucose standard (10 g/100 ml)	Sucrose standard (10 g/100 ml)	50:50 Fructose:glucose standard (5 g/100 ml each)	
Test 1 (g/100 ml)	9.6	10	9.7	5.2	5.1
Test 2 (g/100 ml)	10.1	9.5	8.16	4.8	5.3
Test 3 (g/100 ml)	9.9	9.9	9.16	4.9	4.9
Mean ± s.d.	9.9 ± 0.3	9.8 ± 0.3	9.0 ± 0.8	5.0 ± 0.2	5.1 ± 0.2
Coefficient of variation	2.6%	2.7%	8.7%	4.2%	3.9%

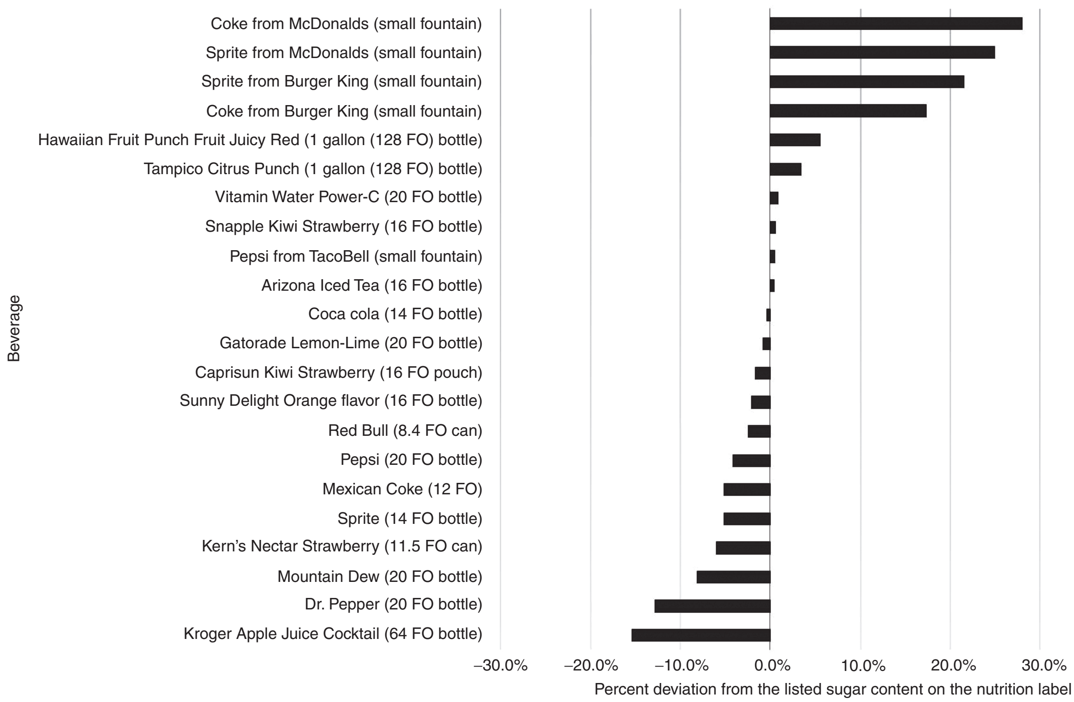

Figure 1 Total sugar content from high-performance liquid chromatography analysis compared to nutrition facts. FO, fluid ounce.

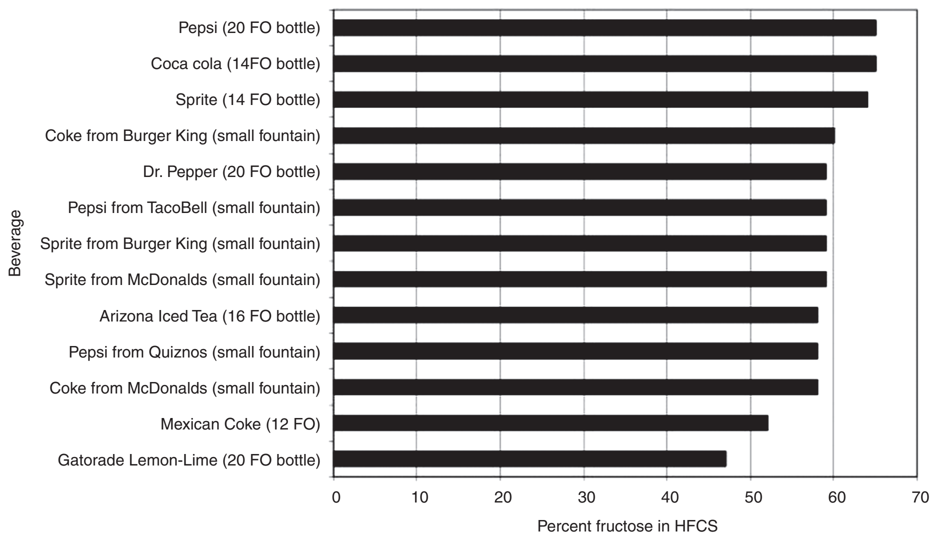

Figure 2 Estimate of the percent fructose used in high fructose corn syrup as assessed by high-performance liquid chromatography analysis. FO, fluid ounce; HFCS, high fructose corn syrup.

listed values (30 and 32 g of sugar per 12 FO on McDonalds and Burger King websites, respectively).

Fructose-to-glucose ratio

As shown in **Figure 2**, the fructose-to-glucose ratio of the drinks containing HFCS as the exclusive source of fructose revealed that the percentage of fructose was nearly always higher than 55%, with a mean of 59%. All of the soft drinks, with the exception of the Mexican Coca-Cola, are 58% fructose or above, and the three most popular soft drinks (Coca-Cola, Sprite, and Pepsi) contained 64–65% fructose.

Within-brand variation in fructose-to-glucose ratio

As shown in **Table 2**, for the three types of beverages that were tested in multiple samples (Coca-Cola, Sprite, and Pepsi), there was variation in the data given on the food label/nutrition facts online. The nutrition facts for the fast food drinks reported less sugar per FO than did the bottled drinks. However, as noted above, the fountain drinks contained a higher concentration of sugar than was listed on the company websites. As tested by the laboratory, there was only a small variation in total sugar content within each of the three soft drinks and the fountain samples had a similar amount of total sugar to the bottled samples.

Table 2 Sugar content of popular sugar-sweetened beverages: published nutrition facts compared to sugar analysis by HPLC

Drink (container type)	Type of sugar listed on label/ nutrition facts	Sugar content from label/ nutrition facts (g/100 ml)[a]	Sugar content by HPLC Fructose (g/100 ml)	Glucose (g/100 ml)	Sucrose (g/100 ml)	Total sugar (g/100 ml)
Coca-Cola (14 FO bottle)	HFCS	11.1	7.2	3.9	<0.05	11.1
Coca-Cola (McDonalds fountain)	HFCS	8.5	6.3	4.5	<0.05	10.8
Coca-Cola (Burger King fountain)	HFCS	9.0	6.3	4.3	<0.05	10.6
Mexican Coca-Cola (12 FO bottle)	Sugar	11.0	5.4	5.0	<0.05	10.4
Sprite (14 FO bottle)	HFCS	10.9	6.6	3.7	<0.05	10.3
Sprite (McDonalds fountain)	HFCS	8.2	6.1	4.2	<0.05	10.3
Sprite (Burger King fountain)	HFCS	9.0	6.5	4.5	<0.05	11.0
Pepsi (20 FO bottle)	HFCS	11.8	7.4	3.9	<0.05	11.4
Pepsi (TacoBell fountain)	HFCS	11.4	6.7	4.7	<0.05	11.5
Pepsi (Quiznos fountain)	HFCS	Unknown	6.6	4.8	<0.05	11.3
Capri Sun Strawberry Kiwi (pouch)	Sugar, concentrated juices	9.0	3.0	2.8	3	8.9
Arizona iced tea (16 FO bottle)	HFCS	10.1	5.9	4.3	<0.05	10.2
Hawaiian Fruit Punch (128 FO bottle)	HFCS, concentrated juices (clarified pineapple, orange, passionfruit, apple)	8.5	5.2	3.7	<0.05	8.9
Kroger Apple Juice Cocktail (64 FO bottle)	HFCS, apple juice concentrate	12.7	5.3	5.0	0.44	10.7
Tampico Citrus Punch (128 FO bottle)	HFCS, concentrate (orange, lemon, tangerine, lime)	11.4	5.4	6.5	<0.05	11.8
Gatorade Lemon-Lime (20 FO bottle)	HFCS, sucrose syrup	5.9	2.1	2.4	1.44	5.9
Mountain Dew (20 FO bottle)	HFCS, orange juice concentrate	13.1	7.0	5.0	<0.05	12.0
Dr. Pepper (20 FO bottle)	HFCS	11.4	5.9	4.1	<0.05	10.0
Sunny Delight Orange flavor (16 FO bottle)	HFCS, concentrate (orange, tangerine, apple, lime, grapefruit)	7.6	4.3	3.1	0	7.5
Kern's Nectar Strawberry (11.5 FO can)	HFCS, strawberry puree concentrate, sugar	13.5	5.6	6.5	0.63	12.7
Snapple Kiwi Strawberry (16 FO bottle)	Sugar, concentrated juices (kiwi,, strawberry, vegetable)	11.0	4.9	4.8	1.38	11.1
Vitamin Water Power-C (20 FO bottle)	Cane sugar, crystalline fructose, vegetable juice (color)	5.5	4.0	0.7	0.78	5.5
Red Bull (8.4 FO can)	sucrose, glucose	10.9	1.9	3.6	5.11	10.6

HFCS, high fructose corn syrup; HPLC, high-performance liquid chromatography.
[a]Grams per fluid ounce from the label were converted to grams per 100 ml using the conversion factor of 100 ml = 3.38140227 fluid ounces.

The samples of Coca-Cola ranged from 37.5 to 39.3 g/12 FO, the Sprite ranged from 36.6 to 38.9 g/12 FO, and the Pepsi ranged from 40.2 to 40.7 g/12 FO. Despite very little variation in total sugar content, there was more substantial variation in the fructose-to-glucose ratio within each of the drink types. For Coca-Cola, the fructose-to-glucose ratio varied from 58:42 to 65:35 for the three United States samples. The Mexican Coca-Cola sample had a fructose-to-glucose ratio of 52:48. The fructose-to-glucose ratio of the three samples of Sprite ranged from 59:41 to 64:36 and the three samples of Pepsi ranged from 58:42 to 65:35. Overall, the bottled (US) samples of these three beverages were at the upper end of the fructose-to-glucose ratio, i.e., with fructose estimates of 64–65%, whereas the fountain samples contained less fructose as compared to glucose, with fructose percentages in the 58–59% range.

Types of sugar listed vs. types of sugar detected

As shown in Table 2, there were differences in the types of sugar listed on the label/nutrition facts as compared to the results from the laboratory assays. For example, for the Mexican Coca-Cola sample, the label lists only "sugar," but no sucrose was detected by HPLC. Instead, the laboratory analysis detected a 52:48 ratio of free fructose-to-glucose. Vitamin water also tested positive for glucose (0.7 g per 5.5 g/100 ml of total sugar) but the ingredient list only reports cane sugar and crystalline fructose as sweeteners. Finally, the Red Bull tested positive for fructose (1.9 per 10.9 g/100 ml of total sugar) whereas the ingredient list names sucrose and glucose as sweeteners.

DISCUSSION

The results of the objective HPLC analyses reveal several important findings: (i) The total sugar content of popular sugar-sweetened beverages varies from the information provided by the manufacturer/vendor with some having more and some having less sugar than the label; (ii) The fructose-to-glucose ratio in the HFCS used in various beverages varies and is nearly always higher than 55%, with several major brands at 65% fructose, and there is within-brand variation in the fructose-to-glucose ratio in different sources of drinks, i.e., bottle vs. fountain; and (iii) The type of sugar listed on the label is not always consistent with the type of sugar detected by the HPLC analysis. The potential implications of each of these findings is discussed below.

First, the variation in total sugar content, which ranged from 85% to 128% of what was listed on the nutrition facts, can cause mis-estimates of sugar consumption both for consumers and for researchers. The nutrition facts for the bottled samples of Coke, Sprite, and Pepsi were fairly accurate, with samples testing between 95 to 100% of what was listed on the label. The Mountain Dew and Dr. Pepper samples tested lower than what was listed on the nutrition facts, with laboratory results of 87% and 92%, respectively. In contrast to the bottled samples, the nutrition facts for the fountain drinks underestimated the total sugar content as compared to the laboratory results. For example, as assessed by the laboratory, on average the total sugar content of Coke, Sprite, and Pepsi from the soda fountains was 119% of what was listed on the published nutrition facts. A likely explanation of this discrepancy could be that the sugar content listed on the company nutrition facts may factor in the ice served with the beverage, such that a cup that holds 12 FO may only contain 10 FO of soda plus ice. However, some consumers order their beverages without ice and in this case the total sugar content of the fountain beverage is underestimated by ~6–8 g per 12 FO, based on the nutrition facts. Another potential explanation could be that the soda fountains are not properly calibrated which could lead to a higher ratio of syrup to soda water. Finally, some of the discrepancy could be caused because fountain drinks have a greater exposure time and surface area to volume ratio than canned and bottled beverages, which could cause some of the water to evaporate, therefore leaving the drink in a more concentrated form. To minimize this type of error for our analysis, we transferred the fountain samples into test tubes within 15 min of purchase.

Our results suggest that more testing of actual vs. reported sugar content of sugar-sweetened beverages are in order in general, and in terms of fountain drinks, there should be information on the fast food company in-store menus and websites regarding whether the nutrition facts reflect displacement by ice. When considering our findings, it is important to note that according to the FDA codes, 12 samples need to be tested to evaluate labeling compliance and it is acceptable for products to contain up to 120% of the stated content for nutrients including sugar (23). Therefore this analysis does not mean to suggest that manufacturers are not in compliance with FDA standards, but does suggest that more evaluation is potentially in order. Considering that the average American drinks 50 gallons of soda and other sweetened beverages each year (11), it is important that we have more precise information regarding what they contain, including a listing of the fructose content. The overall consumption of added sugar is of concern as is the composition of the sugar. Given the large variation and lack of information regarding how much HFCS is used in sugar-sweetened beverages, combined with the evidence that shows that increased fructose consumption is particularly harmful for metabolic health, the public should take additional caution when consuming these products.

Second, the finding that the fructose-to-glucose ratio of the HFCS used in the beverages was nearly always higher than 55% can have important implications for metabolic health. Fructose is often referred to as a healthy form of sugar in that it is found naturally in fruit. However, as an example, a medium orange has 6 g of fructose along with other important nutrients such as vitamins and fiber, whereas a can of soda contains over 20 g of fructose and little nutritional value other than energy. Considering that fructose, when consumed in excess, is known to be more metabolically detrimental than glucose (14), the use of a higher percentage of fructose, in the case of HFCS, in popular beverages is of concern. Fructose and glucose are both monosaccharides while sucrose, or table sugar, is a disaccharide composed of one molecule of fructose and one molecule of glucose. Therefore, even drinks that are sweetened with natural cane sugar have a fructose content that is half that of the total sugar content, which is sizeable, and based on our results it appears that drinks sweetened with HFCS have even higher than 55% fructose.

Despite their very similar chemical structure, fructose and glucose are absorbed and metabolized by completely different pathways. Fructose is absorbed through the GLUT-5 receptor in the gut (24), and in contrast to glucose, is metabolized almost entirely in the liver by a pathway that is not dependent on insulin (25). Accordingly, there is evidence to show that fructose consumption does not stimulate insulin secretion or leptin production by adipose tissue (26,27) and thereby is thought to contribute more directly to weight gain (27). Also, excess fructose consumption has been shown to be more related to the specific accumulation of visceral fat and associated metabolic risk factors, such as insulin resistance, than is excess glucose consumption (14). Fructose consumption has also been shown to have a potential negative impact on cardiovascular health: for example, as compared to glucose, fructose consumption has been shown to prompt an acute rise in blood pressure (28) and in triglyceride synthesis (26,27,29).

Because soft drinks and sweetened beverages are major sources of fructose in the American diet, it is important to accurately quantify how much fructose is contained in these beverages. However, due to a lack of more precise dietary databases, leading papers from the literature that explore trends in fructose consumption, such as recent work by Duffey and Popkin (30) as well as by Marriott (31), use standard estimates from the USDA of 42% or 55% depending on the product type, and the authors state that more precise data regarding the fructose content in HFCS is needed. Contrary to the standard estimates, our findings show that the HFCS used in popular sugar-sweetened beverages may be as high as 65% fructose. Furthermore, our results also showed variation within brands, such that the bottled soft drinks had a higher ratio of fructose-to-glucose than did the fountain drinks. To put these results into context, for every 100 g of added sugar consumed (equivalent to about two 12 ounce cans of soda per day), the difference between 55:45 HFCS and 65:35 HFCS is equivalent to an additional 10 g per day of fructose. This is equivalent to an 18% higher fructose consumption than would be estimated assuming a value of 55% HFCS.

Third, the potential discrepancies regarding the type of sugar used in a few of the drinks raises concerns about the accuracy of the reporting by the manufacturers. For instance, the Mexican Coca-Cola lists "sugar" on the ingredient list, but the laboratory did not detect any sucrose, but rather near equal amounts of fructose and glucose, results which suggest the use of HFCS. According to the FDA guidelines, the word "sugar" can only be used in reference to sucrose (32). If HFCS is used, it must be listed in the ingredient list of the food label (33). In addition to the Mexican Coca-Cola, the results for the Vitamin Water and the Red Bull do not entirely match the ingredient list. The 0.7 g glucose per 100 ml detected in the Vitamin Water, though small, is surprising considering that the listed ingredients are cane sugar and crystalline fructose. This is not likely to be explained by laboratory error considering that the sucrose and fructose standard solutions did not test positive for glucose. Similarly, the 1.9 g of fructose per 100 ml detected in the Red Bull is not consistent with the ingredient list of sucrose and glucose. This result is also not likely to be explained by laboratory error given that the sucrose standard solution tested a false positive for fructose at a low level of 0.26/100 ml, and thus the fructose detected in the Red Bull is seven times that of the fructose detected in the sucrose standard solution. The unexpected glucose detected in the Vitamin Water and the fructose detected in the Red Bull could potentially be explained by the inclusion of HFCS.

There are several limitations that should be noted regarding this study. Considering that only one laboratory was used for the testing and samples were only purchased in Los Angeles, these results are not meant to be conclusive or generalizable, but rather exploratory. Though only one laboratory was used, the testing in triplicate of the standard solution helps to quantify and minimize error. However, the current design does not account for potential changes over time due to sampling errors, fluid shifts, contamination, or potential evaporation of the drinks themselves. Further testing could be conducted with new samples of the same beverages at the same laboratory to address some of these potential errors, and analysis could also be conducted at multiple laboratories to explore potential variation by laboratory or by analysis technique. In addition, future testing of samples purchased from other areas of the country would give useful information about potential variation by lot or by production plant.

Furthermore, in addition to an examination of beverages, future analyses could also be conducted of solid foods that contain HFCS, such as baked goods and candy, in order to compare the fructose content in HFCS as well as the types of sugar used in various products as compared to what is listed on the food labels It would also be interesting to analyze the sugar content of diet beverages as well, to verify the type of sweeteners that are used. Other studies have previously shown error in the actual nutritional content of processed foods, as assessed by an independent laboratory, as compared to what is reported on food labels, such as in the recent work of Urban *et al.* (34). Therefore, problems of this nature are not limited to HFCS. However, the results of the current analysis are useful considering that little information is available regarding what formulations of HFCS are used by manufacturers and there are few guidelines regarding labeling of products that use HFCS. For instance, food labels do not currently include information on fructose content *per se*, but rather report the total and added sugar content of the product. Furthermore, it appears that sometimes HFCS may be used in a given product and not listed on the food label, suggesting that in addition to standard mis-estimates of quantity, there is also likely a problem of disclosure of ingredient types.

This objective laboratory analysis of popular sugar-sweetened beverages provides new data which raises concerns about the accuracy of the estimates for total sugar listed on food labels, the fructose composition of the HFCS used in popular drinks, as well as the types of sugar actually used in beverages as compared to what is listed. Given our findings, future analyses should be conducted to examine the sugar content and composition of drinks, and particularly the fructose content of HFCS. If the fructose content of popular drinks is actually 65% rather than 55%, then fructose intake would be ~18% higher than previously estimated. Therefore, our results have important implications for estimates of fructose consumption and of the relationship between fructose consumption and metabolic health.

ACKNOWLEDGMENTS

This study was supported by USC/NCI Transdisciplinary Research on Energetics and Cancer (U54 CA 116848). We thank the following individuals from the USC Childhood Obesity Research Center for contributing to this project: Tanya Alderete for assisting with the preparation of the samples and the standard solutions; and Kim-Anne Le, PhD, for editorial contributions. No compensation was provided for these contributions.

DISCLOSURE

The authors declared no conflict of interest.

REFERENCES

1. Babey SH, Jones M, Yu H, Goldstein H. Bubbling over: soda consumption and its link to obesity in California. *Policy Brief UCLA Cent Health Policy Res* 2009;1–8.
2. Ludwig DS, Peterson KE, Gortmaker SL. Relation between consumption of sugar-sweetened drinks and childhood obesity: a prospective, observational analysis. *Lancet* 2001;357:505–508.
3. Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight gain: a systematic review. *Am J Clin Nutr* 2006;84:274–288.
4. Vartanian LR, Schwartz MB, Brownell KD. Effects of soft drink consumption on nutrition and health: a systematic review and meta-analysis. *Am J Public Health* 2007;97:667–675.
5. 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;79:537–543.
6. Fung TT, Malik V, Rexrode KM *et al*. Sweetened beverage consumption and risk of coronary heart disease in women. *Am J Clin Nutr* 2009;89:1037–1042.
7. Assy N, Nasser G, Kamayse I *et al*. Soft drink consumption linked with fatty liver in the absence of traditional risk factors. *Can J Gastroenterol* 2008;22:811–816.
8. Palmer JR, Boggs DA, Krishnan S *et al*. Sugar-sweetened beverages and incidence of type 2 diabetes mellitus in African American women. *Arch Intern Med* 2008;168:1487–1492.
9. Schulze MB, Manson JE, Ludwig DS *et al*. Sugar-sweetened beverages, weight gain, and incidence of type 2 diabetes in young and middle-aged women. *JAMA* 2004;292:927–934.
10. Davis JN, Ventura EE, Weigensberg MJ *et al*. The relation of sugar intake to beta cell function in overweight Latino children. *Am J Clin Nutr* 2005;82:1004–1010.
11. Duffey KJ, Popkin BM. Shifts in patterns and consumption of beverages between 1965 and 2002. *Obesity (Silver Spring)* 2007;15:2739–2747.
12. Bray GA. How bad is fructose? *Am J Clin Nutr* 2007;86:895–896.
13. Tappy L, Lê KA. Metabolic effects of fructose and the worldwide increase in obesity. *Physiol Rev* 2010;90:23–46.
14. Stanhope KL, Schwarz JM, Keim NL *et al*. Consuming fructose-sweetened, not glucose-sweetened, beverages increases visceral adiposity and lipids and decreases insulin sensitivity in overweight/obese humans. *J Clin Invest* 2009;119:1322–1334.
15. Taylor EN, Curhan GC. Fructose consumption and the risk of kidney stones. *Kidney Int* 2008;73:207–212.
16. Asselman M, Verkoelen CF. Fructose intake as a risk factor for kidney stone disease. *Kidney Int* 2008;73:139–140.
17. Johnson RJ, Segal MS, Sautin Y *et al*. Potential role of sugar (fructose) in the epidemic of hypertension, obesity and the metabolic syndrome, diabetes, kidney disease, and cardiovascular disease. *Am J Clin Nutr* 2007;86:899–906.
18. Nakagawa T, Hu H, Zharikov S *et al*. A causal role for uric acid in fructose-induced metabolic syndrome. *Am J Physiol Renal Physiol* 2006;290:F625–F631.
19. The Corn Refiners Association. Sweet Surprise.<http://www.sweetsurprise.com>. Accessed 12 Jan 2010.
20. Hanover LM, White JS. Manufacturing, composition, and applications of fructose. *Am J Clin Nutr* 1993;58:724S–732S.
21. White JS. Straight talk about high-fructose corn syrup: what it is and what it ain't. *Am J Clin Nutr* 2008;88:1716S–1721S.
22. AOAC International. *Official Methods of Analysis of the AOAC*. AOAC International: Arlington VA, 1990.
23. Food and Drug Administration. *Nutrition Labelling of Foods*, 21 CFR 101.9(5), 2005.
24. Douard V, Ferraris RP. Regulation of the fructose transporter GLUT5 in health and disease. *Am J Physiol Endocrinol Metab* 2008;295: E227–E237.
25. Gaby AR. Adverse effects of dietary fructose. *Altern Med Rev* 2005;10: 294–306.
26. Teff KL, Grudziak J, Townsend RR *et al*. Endocrine and metabolic effects of consuming fructose- and glucose-sweetened beverages with meals in obese men and women: influence of insulin resistance on plasma triglyceride responses. *J Clin Endocrinol Metab* 2009;94:1562–1569.
27. Stanhope KL, Havel PJ. Endocrine and metabolic effects of consuming beverages sweetened with fructose, glucose, sucrose, or high-fructose corn syrup. *Am J Clin Nutr* 2008;88:1733S–1737S.
28. Brown CM, Dulloo AG, Yepuri G, Montani JP. Fructose ingestion acutely elevates blood pressure in healthy young humans. *Am J Physiol Regul Integr Comp Physiol* 2008;294:R730–R737.
29. Parks EJ, Skokan LE, Timlin MT, Dingfelder CS. Dietary sugars stimulate fatty acid synthesis in adults. *J Nutr* 2008;138:1039–1046.
30. Duffey KJ, Popkin BM. High-fructose corn syrup: is this what's for dinner? *Am J Clin Nutr* 2008;88:1722S–1732S.
31. Marriott BP, Cole N, Lee E. National estimates of dietary fructose intake increased from 1977 to 2004 in the United States. *J Nutr* 2009;139: 1228S–1235S.
32. Food and Drug Administration. Code of Federal Regulations Title 21: Direct Food Substances Affirmed as Generally Recognized as Safe. 2008, p. 17.
33. Food and Drug Administration. Code of Federal Regulations Title 21: Direct Food Substances Affirmed as Generally Recognized as Safe. 2008, p. 569.
34. Urban LE, Dallal GE, Robinson LM *et al*. The accuracy of stated energy contents of reduced-energy, commercially prepared foods. *J Am Diet Assoc* 2010;110:116–123.