

## Intake of sugar-sweetened beverages and weight gain: a systematic review<sup>1-3</sup>

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### ABSTRACT

Consumption of sugar-sweetened beverages (SSBs), particularly carbonated soft drinks, may be a key contributor to the epidemic of overweight and obesity, by virtue of these beverages' high added sugar content, low satiety, and incomplete compensation for total energy. Whether an association exists between SSB intake and weight gain is unclear. We searched English-language MEDLINE publications from 1966 through May 2005 for cross-sectional, prospective cohort, and experimental studies of the relation between SSBs and the risk of weight gain (ie, overweight, obesity, or both). Thirty publications (15 cross-sectional, 10 prospective, and 5 experimental) were selected on the basis of relevance and quality of design and methods. Findings from large cross-sectional studies, in conjunction with those from well-powered prospective cohort studies with long periods of follow-up, show a positive association between greater intakes of SSBs and weight gain and obesity in both children and adults. Findings from short-term feeding trials in adults also support an induction of positive energy balance and weight gain by intake of sugar-sweetened sodas, but these trials are few. A school-based intervention found significantly less soft-drink consumption and prevalence of obese and overweight children in the intervention group than in control subjects after 12 mo, and a recent 25-week randomized controlled trial in adolescents found further evidence linking SSB intake to body weight. The weight of epidemiologic and experimental evidence indicates that a greater consumption of SSBs is associated with weight gain and obesity. Although more research is needed, sufficient evidence exists for public health strategies to discourage consumption of sugary drinks as part of a healthy lifestyle. *Am J Clin Nutr* 2006;84:274-88.

**KEY WORDS** Sugar-sweetened beverages, soft drinks, soda, fruit drinks, weight gain, obesity, added sugar, energy compensation

### INTRODUCTION

Over the past 2 decades, obesity has escalated to epidemic proportions in the United States and many countries around the world. According to the World Health Organization (WHO), >1 billion adults throughout the world are overweight, with a body mass index (BMI; in kg/m<sup>2</sup>)  $\geq 25$ . Of these, at least 300 million are considered obese (BMI  $\geq 30$ ; 1). In the United States alone, an estimated 129.6 million persons, or 64% of the population aged 20-74 y, are overweight, and 30% of those 129.6

million are considered obese (2, 3). Similar trends are being seen among children and adolescents, which could lead to serious health complications in adulthood (4). Overweight and obesity are associated with numerous comorbidities of great public health concern, including hypertension, cardiovascular disease, diabetes, depression, and breast, endometrial, colon, and prostate cancers (5, 6). The decreases in productivity and quality of life that result from overweight and obesity are linked to elevated medical, psychological, and social costs (7).

Although obesity results from an imbalance of energy homeostasis, the true mechanisms underlying this process and effective strategies for prevention and treatment remain unknown. In general, obesity reflects complex interactions of genetic, metabolic, cultural, environmental, socioeconomic, and behavioral factors (2). National survey data in the United States have indicated that, over the past 20 y, concomitant with the increase in rates of overweight and obesity, consumption of carbohydrates, largely in the form of added sugars, has increased (8, 9). Between 1977 and 1996, the proportion of energy from the consumption of caloric sweeteners rose from 13.1% to 16.0% (a 22% increase), and in 1994-1996, > 30% of carbohydrates consumed in the United States by persons aged  $\geq 2$  y came from caloric sweeteners (10). As a result, the 2000 (11) and 2005 (12) *Dietary Guidelines for Americans* advised the public to choose beverages and foods that will decrease their intake of added sugars, and the WHO has suggested that added sugars should provide no more than 10% of dietary energy (13).

Current estimates are that the mean intake of added sugar by Americans accounts for 15.8% of total energy and that the largest source of these added sugars is nondiet soft drinks, which account

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for 47% of total added sugars in the diet (14). The term *soft drink* encompasses sodas along with other sugar-sweetened beverages such as fruit drinks, lemonade, and iced tea. The term *soda* encompasses sugar-sweetened carbonated beverages such as colas. Consumption of these beverages was shown to increase by 135% between 1977 and 2001 (15). It is estimated that, during this time, daily caloric sweetener consumption in the United States increased by 83 kcal per person, of which 54 kcal/d is from soda (10). In the United States, on average, a 12-oz serving [12 oz = 1 can of soda (or 1 soda) = 1 serving] of soda provides 150 kcal and 40–50 g sugar in the form of high-fructose corn syrup [(HFCS) ≈45% glucose and 55% fructose], which is equivalent to 10 teaspoons of table sugar. If these calories are added to the typical US diet without reducing intake from other sources, 1 soda/d could lead to a weight gain of 15 lb or 6.75 kg in 1 y (16).

Paralleling the pattern of soda consumption is that of the consumption of fruit drinks and fruitades (drinks made by adding water to powder or crystals), which are similarly sweetened and are often consumed in large amounts by toddlers and young children. Of the total 83 kcal/d increase in the consumption of caloric sweetener, 13 kcal/d is estimated to have come from fruit drinks (10). Consumption of these fruit drinks and soda represents nearly 81% of the increase in caloric sweetener intake across 2 recent decades in the United States (10). In addition, the increased consumption of HFCS, the prevailing sweetener used to flavor calorically sweetened beverages in the United States, has been found to mirror the growth of the obesity epidemic (17–19). It has been suggested that the intake of sugar-sweetened beverages may promote weight gain and obesity by increasing overall energy intake (20). Several studies evaluated the relation between the intake of sugar-sweetened beverages and weight gain and obesity, but discrepant results made it difficult to ascertain whether a direct link exists. This review critically examines the current evidence for an association between intake of sugar-sweetened beverages and weight gain and obesity.

## MATERIALS AND METHODS

Relevant English-language articles were identified by searching the MEDLINE database (National Library of Medicine, Bethesda, MD) of articles published between 1966 and May 2005 for cross-sectional, prospective cohort, and experimental studies of the intake of sugar-sweetened beverages (soft drinks, soda, fruitades, fruit drinks, sports drinks, sweetened iced tea, squashes, and lemonade) and weight gain, obesity, or both. Key words such as “soda,” “soda pop,” and “sugar-sweetened beverage” hedged with “weight gain,” “overweight,” and “obesity” were used in the primary search strategy, as well as in a subsequent search using medical subheading (MeSH) terms. Additional published reports were obtained by cross-matching references of selected articles. Selection of articles was restricted to those in the English language that included ≥1 endpoints evaluating body size or weight measurements in humans—ie, BMI, BMI *z* score, weight in kilograms, or weight in pounds. Restriction based on the age of the study participants was not used because there is large variability in eligible age groups among studies. For prospective cohort studies, a duration of ≥6 mo was required for inclusion in our review, to ensure that sufficient follow-up time was provided to effectively evaluate the relation between beverage consumption and weight change. After the data were examined for relevance and eligibility, 30 articles were

identified and extracted (by VSM and MBS). A meta-analysis was attempted, but the degree of heterogeneity among study designs, particularly with respect to the age groups of participants and to outcome assessment, was prohibitive, and therefore a more qualitative assessment is presented. Greater weight is given to large cross-sectional studies with > 10 000 participants, prospective cohort studies, and experimental interventions with longer follow-up and large numbers of participants. The nature of the dietary assessment method was also evaluated; we considered the use of food-frequency questionnaires (FFQs) and repeated measures of intake to be optimal for prospective cohort studies. The age of the participants is also considered because assessment of beverage consumption and weight change in very young children is challenging and can be difficult.

## RESULTS

The key word search initially identified a total of 264 citations—260 from MEDLINE and 4 from the MeSH search. After we screened these publications for English language and established whether they were conducted in humans and contained relevant subject matter pertaining to beverage consumption, body weight, or both, we deemed 72 to be potentially eligible. Forty-seven of the 72 articles were excluded because they did not meet the eligibility criteria (23 did not assess soft drink intake or report weight change data, 12 were editorials or commentaries, 11 were reviews, and 1 prospective cohort study was too short). Five investigations were added after the original extraction. Thus, 30 studies were eligible for review. Of these, 15 are cross-sectional studies (21–35), 10 are prospective cohort studies (25, 28, 36–43), and 5 are clinical trials and interventions (44–48). Two studies (25, 28) report both prospective and cross-sectional findings.

### Cross-sectional studies

Findings from cross-sectional studies (**Table 1**) suggest a positive trend in the relation between the intake of sugar-sweetened beverages and overweight or obesity. Of the 15 studies included here, 13 involved children and adolescents and 2 involved adults. Six of the studies of children and adolescents (21, 23, 25, 29, 31, 33) found a significant positive association between the intake of sugar-sweetened beverages and overweight or obesity. Three studies suggested positive associations (26, 27, 35), although the associations were not significant, and 3 studies (22, 24, 30) found no significant association (direction of association not reported). One study (34) had inconsistent findings and reported a negative association of high and low quartiles of drink intake with added-sugar drinks (soft drinks and lemonade) and BMI in 8th-grade girls ( $P = 0.013$ ) and a positive association in 4-y-old boys ( $P = 0.055$ ). Some of the most noteworthy findings came from the Growing Up Today (GUT) study (25) and combined National Health and Nutrition Examination Surveys [(NHANES) 21]), both of which included > 10 000 children and adolescents. Findings from the GUT study showed that, in girls, the consumption of sugar-added beverages was positively associated with increased weight (0.06 increase in BMI/serving,  $P = 0.04$ ). The third NHANES (NHANES III) combined with earlier versions of NHANES showed that consumption of soft drinks contributed a higher proportion of energy in overweight than in normal-weight subjects in each age and sex group (2–5 y: 3.1% versus 2.4%; 6–11 y: 5.4% versus 4%; males,



**TABLE 1**  
Cross-sectional studies<sup>1</sup>

Reference	Population	Baseline age or age range	Weight measure	Beverage category	Results
Anderson et al (22)	3139 Children (1609 girls, 1530 boys); Norway	8–14	BMI (median): girls (grade 8, 1993), 18.9 (18.6) <sup>2</sup> ; girls (grade 8, 2000), 19.1 (18.6); girls (grade 4, 2000), 17.1 (16.7); boys (grade 8, 1993), 19.1 (18.7); boys (grade 8, 2000), 19.0 (18.4); boys (grade 4, 2000), 17.1 (16.7)	Sweetened soft drinks	No significant association between sweetened soft drinks and overweight ( $P > 1.0$ ) (data not shown)
Ariza et al (23)	250 Children (123 girls, 127 boys); Hispanic American	5–6	23% of Children were overweight ( $\geq$ 95th percentile of weight-for-height)	Sweetened beverages, milk, juice	Overweight children more likely than nonoverweight children to consume sweetened beverages daily (67% vs 39%; $P = 0.03$ ); daily consumption associated with overweight compared with less-than-daily consumption (OR: 3.7; 95% CI: 1.2, 11.0).
Bandini et al (24)	43 Adolescents (23 female, 20 male); Boston	12–18	Percentage body fat: nonobese, 21.1 $\pm$ 7.6 <sup>3</sup> ( $n = 22$ ); obese, 43.1 $\pm$ 7.2 ( $n = 21$ )	Soda	No difference in percentage of energy from soda between obese (5.9 $\pm$ 4.9%) and nonobese (6.0 $\pm$ 4.9%) subjects
Berkey et al (25)	16 679 Children (8941 girls, 7738 boys); Growing Up Today study	9–14	BMI: girls aged 9 y, 17.47 $\pm$ 2.84; girls aged 14 y, 20.52 $\pm$ 3.09; boys aged 9 y, 17.77 $\pm$ 2.90; boys aged 14 y, 20.82 $\pm$ 3.22 <sup>4</sup>	Sugar-sweetened drinks, fruit juice, diet soda, milk	Girls who drank more sugar-added beverages were heavier (BMI rose 0.06 per serving; $P = 0.04$ ); data for boys not shown
Forshee et al (26)	2216 Adolescents (48.5% female, 51.1% male); NHANES III	12–16	Mean BMI: females, 21.9; males, 21.5	Fruit drinks, diet fruit drinks, soda, diet soda, coffee, tea, wine, beer, spirits	Positive nonsignificant association between soda and BMI; inverse nonsignificant association between fruit drinks and BMI via 24-h recall
Forshee and Storey (27)	3311 Children and adolescents (1624 female, 1687 male); CSFII	6–19	Not given	Milk, soda, diet soda, fruit drinks, diet fruit drinks, citrus juice, other juice	Positive nonsignificant association between soda and BMI; inverse nonsignificant association between fruit drinks and BMI
French et al (28)	3552 Adults (1913 female, 1639 male); Healthy Worker Project, USA	Females, 37.3 $\pm$ 10.7; males, 39.1 $\pm$ 9.8	BMI: females, 25.1 $\pm$ 5.5; males, 26.6 $\pm$ 3.9	Soda	Significant ( $P = 0.03$ ) association between soda consumption and weight in females; $\beta = 0.47$ , SE = 0.22; a weaker association in males; $\beta = 0.33$ , SE = 0.21 ( $P = 0.13$ ) <sup>5</sup>
Giammattei et al (29)	385 Children (199 girls, 186 boys); California	11–13	BMI z score: girls, 0.53 $\pm$ 1.0; boys, 0.63 $\pm$ 1.05	Soda, diet soda	Those who consumed $\geq$ 3 soft drinks (soda and diet soda)/d had BMI z scores 0.51 higher (95% CI: 0.17, 0.85, $P = 0.003$ ), had 4.4% more body fat, and were more likely to have BMIs $\geq$ 85th percentile than did those who consumed < 3 soft drinks/d (58.1% vs 33.2%; $P = 0.006$ )
Gibson (29)	1586 Children; National Diet and Nutrition Survey, UK	1.5–4.5	Difficult to discern from figure	Soft drinks	No significant association between BMI and the proportion of soft drinks in the diet (data not shown)
Gillis and Bar-Or (31)	181 Children and adolescents (106 female, 75 male)	4–16	BMI: obese, 29 $\pm$ 5.0 ( $n = 91$ ); nonobese, 17 $\pm$ 1.5 ( $n = 90$ )	Soda, sugar-sweetened beverages	Obese subjects consumed more sugar-sweetened drinks ( $P < 0.002$ ) and a combination of sugar-sweetened drinks and soda ( $P < 0.05$ ; $P < 0.002$ for boys alone) than did nonobese subjects; no significant difference between groups in soda consumption
Liebman et al (32)	1817 Adults (889 female, 928 male); Wellness in the Rockies Study	18–99	BMI: females aged < 50 y, 27.3 $\pm$ 6.7; females aged > 50 y, 27.2 $\pm$ 5.7; males aged < 50 y, 27.5 $\pm$ 4.9; males aged > 50 y, 27.3 $\pm$ 4.8	Sugar-sweetened beverages, soda, diet soda	Probability of overweight greater in subjects who drank $\geq$ 1 soda/wk than in those who drank < 1 soda/wk (70% vs 47% in females; aged $\geq$ 50 y; 77% vs 58% in males aged $\geq$ 50 y; $P < 0.05$ ) Probability of obesity greater in subjects who drank $\geq$ 1 soda/wk than in those who drank < 1 soda/wk (32% vs 18% in females; aged $\geq$ 50 y; 33% vs 18% in females aged < 50 y; 26% vs 17% in males; aged $\geq$ 50 y; $P < 0.05$ )

(Continued)

TABLE 1 (Continued)

Reference	Population	Baseline age or age range	Weight measure	Beverage category	Results
Nicklas et al (33)	1562 Children (51% girls, 49% boys); Bogalusa Heart Study	y 10	24% overweight, 76% normal-weight	Sweetened beverages, juice, milk	Consumption of sweetened beverages (58% soda, 20% fruit drinks, 19% tea, and 3% coffee) was significantly ( $P < 0.001$ ) associated with overweight (OR: 1.33; 95% CI: 1.12, 1.57, after adjustment for energy, age, study year, ethnicity, sex, and sex $\times$ ethnicity interaction)
Overby et al (34)	2206 Children (810 grade 4, 1005 grade 8, and 391 aged 4 y)	4–13	BMI ( $\bar{x} \pm$ SD) for Q1 and Q4 of percentage of energy consumed from added sugar: girls aged 4 y, 15.7 $\pm$ 1.5 (Q1) and 16.1 $\pm$ 1.7 (Q4), $P = 0.341$ ; grade 4 girls, 17.4 $\pm$ 2.8 (Q1) and 16.8 $\pm$ 3 (Q4), $P = 0.236$ ; grade 8 girls, 19.4 $\pm$ 3.1 (Q1) and 18.5 $\pm$ 2.2 (Q4), $P = 0.013$ ; boys aged 4 y, 15.7 $\pm$ 1.3 (Q1) and 16.3 $\pm$ 1.4 (Q4), $P = 0.055$ ; grade 4 boys, 16.8 $\pm$ 2.5 (Q1) and 17.2 $\pm$ 2.8 (Q4), $P = 0.312$ ; grade 8 boys, 18.9 $\pm$ 2.3 (Q1) and 18.9 $\pm$ 2.7 (Q4), $P = 0.816$	Soft drinks, lemonade	Negative association between added sugar and BMI in grade 8 girls ( $P = 0.013$ ) and a positive association in 4-y-old boys ( $P = 0.055$ ); soft drinks contributed an average of 40% of added sugar
Rodriguez-Artalejo et al (35)	1112 Children (555 girls, 557 boys); Spain	6–7	BMI 17.0 $\pm$ 2.4	Sweetened soft drinks, bakery items, yogurt	No significant association between sweetened soft drink intake and BMI; difference in BMI between 5th and 1st quartiles of soda intake, 0.4 ( $P > 0.01$ ) <sup>6</sup>
Troiano et al (21)	10 371 Children; NHANES III and earlier surveys	2–19	Not given	Soft drinks	Soft drinks contributed higher proportion of energy in overweight than in nonoverweight subjects (aged 2–5 y, 3.1% vs 2.4%; aged 6–11 y, 5.4% vs 4%; males aged 12–19 y, 10.3% vs 7.6%; females aged 12–19 y, 8.6% vs 7.9%; $P$ not given)

<sup>1</sup> BMI measured as kg/m<sup>2</sup>. OR, odds ratio; Q, quartile.

<sup>2</sup> Median; 95th percentile cutoff in parentheses (all such values).

<sup>3</sup>  $\bar{x} \pm$  SD (all such values).

<sup>4</sup> BMI values based on baseline data presented by Berkey et al (98).

<sup>5</sup>  $\beta$  represents the difference in weight between women who reported consuming 1 serving (ie, one 12-oz can) of soda per week and those who reported no soda consumption.

<sup>6</sup> Because of the large number of statistical tests performed, statistical significance was set at  $P < 0.01$ .

12–19y: 10.3% versus 7.6%; females, 12–19 y: 8.6% versus 7.9%; *P* values not reported).

In studies of adults, Liebman et al (32) found a significantly greater probability of overweight in subjects who drank  $\geq 1$  soda/wk than in those who drank  $< 1$  soda/wk (70% compared with 47% of women aged  $\geq 50$  y; 77% compared with 58% of men aged  $\geq 50$  y,  $P < 0.05$ ). The probability of obesity was also significantly greater in subjects who drank  $\geq 1$  soda/wk than in those who drank  $< 1$  soda/wk (32% compared with 18% of women aged  $\geq 50$  y; 33% compared with 18% of women aged  $< 50$  y; 26% compared with 17% of men aged  $\geq 50$  y,  $P < 0.05$ ). Similarly, the findings of French et al (28) indicate that women who consumed 1 soda/wk were 0.47 pounds (0.21 kg) heavier than those who reported no soda consumption ( $P = 0.03$ ). Men consuming 1 soda/wk were 0.33 pounds (0.15 kg) heavier than those who reported no soda consumption, although this difference was not significant ( $P = 0.13$ ).

### Prospective cohort studies

Descriptive characteristics of the prospective cohort studies included in this review are presented in **Table 2**. Six of the 10 studies included here were in children and adolescents (25, 36, 38–40, 42) and 4 were in adults (28, 37, 41, 43).

Four of the studies in children and adolescents found significant positive associations between the intake of sugar-sweetened beverages and greater overweight or obesity (25, 38, 40, 42). During a 3-y follow-up of 11 654 children (25), there was a significant association between soda consumption and weight gain in both boys and girls; boys who increased their soda consumption from the previous year gained weight (0.04 increase in BMI/additional daily serving,  $P = 0.01$ ), and children who increased their soda intake by  $\geq 2$  servings/d from the previous year gained weight (0.14 increase in BMI in boys,  $P = 0.01$ ; 0.10 increase in BMI in girls,  $P = 0.046$ ). Adjustment for energy attenuated the magnitude of the estimated associations, possibly because of the contribution of sugar-sweetened beverages to total energy intake. In a smaller investigation, Ludwig et al (38) found that both baseline consumption of sugar-sweetened beverages and a change in consumption independently predicted change in BMI during 19 mo of follow-up. In the fully adjusted model, BMI increased by 0.18 from baseline for each serving consumed per day (95% CI: 0.09, 0.27;  $P = 0.02$ ). For each additional serving of sugar-sweetened beverage consumed per day, BMI increased by 0.24 (95% CI: 0.10, 0.39;  $P = 0.03$ ) and the odds ratio (OR) of obesity increased by 60% (OR: 1.60; 95% CI: 1.14, 2.24;  $P = 0.02$ ). Phillips et al (40) evaluated the longitudinal relation (from baseline to 4 y after menarche) between the consumption of energy-dense snack (EDS) foods, including soda, and relative weight change during adolescence in a cohort of preadolescent girls with a baseline age of 8–12 y. Subjects in the third and fourth quartiles of percentage of calories from soda had BMI *z* scores an average of 0.17 units higher than those of subjects in the first quartile ( $P < 0.001$ ). Welsh et al (42) assessed the risk of overweight over a 1-y period in low-income children aged 2 and 3 y at baseline by quartile of consumption of sweetened drinks (including soda, fruit drinks, vitamin C-containing juices, and other juices) and baseline weight status. Consumption of sweetened drinks was positively associated with the development of overweight in normal-weight children and the maintenance of overweight over time.

Two studies in children found nonsignificant associations between the intake of sugar-sweetened beverages and BMI. Newby et al (39) examined the association between beverage consumption and changes in weight and BMI in low-income preschool children followed for 6–12 mo. Multivariate regression analysis found no significant association between soda intake and annual changes in BMI, but low intakes and limited variation in the intake of soda and fruit drinks observed in preschool children may have limited the power of the analyses. A small study by Blum et al (36) did not find a significant association between the assessed changes in the consumption of sugary beverages and BMI *z* scores in 166 schoolchildren in a 2-y period.

Only 4 studies have examined the relation between the intake of sugar-sweetened beverages and weight gain in adults. A recent study by Schulze et al (41) evaluated the effect of the intake of sugar-sweetened beverages on weight gain and the incidence of type 2 diabetes in a large cohort of young and middle-aged women during 2 consecutive follow-up periods of 4 y. In both periods, women who increased their consumption of soda from  $\leq 1$  serving/wk to  $\geq 1$  serving/d had significantly ( $P < 0.001$ ) larger increases in weight (multivariate-adjusted  $\bar{x}$ : 4.69 kg during 1991–1995 and 4.20 kg during 1995–1999) and BMI (multivariate-adjusted  $\bar{x}$ : 1.72 during 1991–1995 and 1.53 during 1995–1999) than did women who maintained a low ( $\leq 1$ /wk) or a high ( $\geq 1$ /wk) intake or substantially reduced their intake (from  $\geq 1$ /d to  $\leq 1$ /wk). The lowest increases in weight and BMI were observed in women who reduced their intake from high to low (multivariate-adjusted  $\bar{x}$  increases in weight of 1.34 kg during 1991–1995 and 0.15 kg during 1995–1999; respective multivariate-adjusted  $\bar{x}$  increases in BMI: 0.49 and 0.05). However, weight change in the women who maintained a high consumption of soda and in those who maintained a low consumption did not differ significantly. As part of an investigation of the stability of soft-drink intake from adolescence (aged 11–17 y in 1979–1981) to adulthood (aged 23–27 y in 1991 and 31–35 y in 1999), Kvaavik et al (37) assessed the association between long-term consumption of soft drinks and body weight. After an 8-y follow-up, the authors found slightly higher odds of overweight and obesity in long-term high consumers of soda than in long-term low consumers of soda (both groups made up of both men and women), although these findings were not significant. A recent study evaluated whether the consumption of sugar-sweetened beverages increased the likelihood of weight gain in a Mediterranean population of 7194 men and women ( $\bar{x}$  age: 41 y) who were followed for a median of 28.5 mo (43). The authors found that, of participants with a history of weight gain ( $\geq 3$  kg in the 5 y before baseline), those in the 5th quintile of sweetened-beverage consumption had a 60% greater odds of weight gain during follow-up than did those in the 1st quintile (OR: 1.6, 95% CI: 1.2, 2.1;  $P$  value = 0.02). A nonsignificant positive association was found in participants who had not gained weight in the 5-y period before baseline (OR: 1.10, 95% CI: 0.91, 1.34; 43). Another study with a similar length of follow-up, conducted in 3552 healthy workers in the United States, found that an increased consumption of 1 soda/wk was associated with a small and nonsignificant increase in body weight (28).

### Experimental studies

The descriptive characteristics of experimental trials included in this review are shown in **Table 3**. All 3 short-term feeding trials (44, 46, 47) were conducted in adults, and their findings



**TABLE 2**  
Prospective studies<sup>1</sup>

Reference	Population	Baseline age or age range <sup>y</sup>	Duration of follow-up	Beverage category	BMI, BMI z score, or weight (in kg)		Results as predictors of weight change
					Baseline	Follow-up	
Berkey et al (25)	1 1 654 Children (6636 girls, 5067 boys); Growing Up Today study	9–14	3 y	Sugar-sweetened drinks, fruit juices, diet soda, milk	Girls aged 9 y, 17.47 ± 2.84 <sup>a</sup> ; girls aged 14 y, 20.52 ± 3.09; boys aged 9 y, 17.77 ± 2.90; boys aged 14 y, 20.82 ± 3.22 <sup>b</sup> All subjects: 61.8 ± 11–74.5 ± 14 kg	Not given	Association between sugar-sweetened beverage intake and BMI: girls, $\beta = 0.02$ , SE = 0.012 ( $P < 0.10$ ); boys, $\beta = 0.03$ , SE = 0.014 ( $P < 0.05$ ) <sup>a,b</sup>
Bes-Rastrollo et al (43)	7194 Adults; Seguimiento Universidad de Navarra Study	41	28.5 mo (median)	Sugar-sweetened soft drinks, diet soda, milk	BMI z score, all subjects: 0.47 ± 1.0	Percentage increase in weight (in kg) by quartile of soft drink consumption in subjects with $\geq 3$ kg weight gain in 5 y before baseline: Q1, 41; Q2, 46; Q3, 43; Q4, 46; Q5, 50	Association between sugar-sweetened beverage intake and weight gain in subjects with $\geq 3$ kg weight gain in 5 y before baseline (OR = 1.6; 95% CI: 1.2, 2.4; $P = 0.02$ )
Blum et al (36)	166 School-age children (92 girls, 74 boys); Nebraska	9.3 ± 1.0	2 y	Sugar-sweetened drinks, fruit juice, diet soda, milk	BMI z score, all subjects: 0.47 ± 1.0	BMI z score, all subjects: 0.56 ± 1.0	No significant association between sugar-sweetened beverage intake and year 2 BMI z score ( $\beta = -0.003$ , SE = 0.004; $P > 0.05$ ) <sup>z</sup>
French et al (28)	3552 Adults (1913 females, 1639 males); Healthy Worker Project, USA	Females, 37.3 ± 10.7; males, 39.1 ± 9.8	2 y	Soda	Females, 25.1 ± 5.5; males, 26.6 ± 3.9	Females, 25.2 ± 5.5; males, 26.6 ± 3.8	Positive but nonsignificant association between soda consumption and weight change: females, $\beta = 0.08$ , SE = 0.10 ( $P = 0.39$ ); males, $\beta = 0.11$ , SE = 0.09 ( $P = 0.22$ ) <sup>z</sup>
Kvaavik et al (37)	422 Adults (215 female, 207 male); Oslo Youth Study Survey	23–27	8 y	Soda, diet soda	Females, combined 1979 and 1981 entries: 19.8 ± 2.5; males, combined 1979 and 1981 entries, 19.5 ± 2.6	Females (1999), 23.4 ± 4.1; males (1999), 25.6 ± 3.9	No significant association between soda intake and change in BMI: overweight males, OR: 1.05 (95% CI: 0.46, 2.40); obese males, OR: 2.29 (95% CI: 0.48, 10.96); overweight females, OR: 1.57 (95% CI: 0.46, 5.33); obese females, OR: 0.80 (95% CI: 0.09, 6.85)
Ludwig et al (38)	548 Children (263 girls, 285 boys); Planet Health Intervention and Evaluation project	11.7 ± 0.8	19 mo	Sugar-sweetened drinks, diet soda, fruit juice	20.73 ± 3.99	22.23 ± 4.38	Association between sugar-sweetened beverage intake and BMI ( $\bar{x}$ : 0.24; 95% CI: 0.10, 0.39; $P = 0.03$ ) and odds of obesity (OR: 1.60; 95% CI: 1.14, 2.24; $P = 0.02$ ) <sup>z</sup>
Newby et al (39)	1345 Children (670 girls, 675 boys); North Dakota (WIC)	2–5	6–12 mo	Fruit juice, fruit drinks, milk, soda, diet soda	Girls, 16.4 ± 1.3; boys, 16.7 ± 1.3	Not given	No significant association between soda intake and change in BMI ( $\beta = -0.01$ , SE = 0.02; $P = 0.50$ ), multivariate adjusted
Phillips et al (40)	141 Females; MIT Growth and Development Study	8–12	10 y	Energy-dense snack foods (soda)	BMI z score: -0.27 ± 0.89 ( $n = 166$ )	BMI z score: 0.02 ± 0.79	Association between soda intake and BMI z score: $\beta = -0.17$ for Q3 and Q4 of percentage of calories from soda ( $P < 0.001$ ) <sup>y</sup>
Schulze et al (41)	51 603 Females; Nurses Health Study II	24–44	8 y	Sweetened soft drinks, diet soft drinks, fruit juice	By frequency of soft drink intake: <1/mo, 24.8 ± 5.2; 1–4/mo, 24.2 ± 5.0; 2–6/wk, 24.3 ± 5.5; $\geq 1/d$ , 24.8 ± 6.1	By change in soft drink intake: a) 24.3 ± 4.9; b) 24.4 ± 5.9; c) 25.8 ± 5.8; d) 24.9 ± 5.7 <sup>b,c</sup>	Association between soft-drink intake and weight gain ( $\bar{x}$ ± SE: 4.69 ± 0.20 kg from 1991 to 1995 and 4.20 ± 0.22 kg from 1995 to 1999) and BMI ( $\bar{x}$ ± SE: 1.72 ± 0.07 from 1991 to 1995 and 1.53 ± 0.08 from 1995 to 1999); multivariate adjusted means <sup>1,7</sup>
Welsh et al (42)	10 904 Children (50.1% girls, 49.9% boys); Missouri (WIC)	2–3	1 y	Soda, fruit drinks, vitamin C-containing juices, other juices	75% Of children were normal or underweight, 14.5% were at risk of overweight, and 10.1% were overweight <sup>1,2</sup>	3% Of normal-weight children were overweight at follow-up, 25% of at-risk children were overweight at follow-up, and 67% of overweight children remained overweight	Association between sweet-drink consumption and overweight: baseline normal weight, Q2 (OR: 1.5, 95% CI: 0.9, 2.4); Q3 (OR = 1.4, 95% CI: 0.8, 2.3); Q4 (OR: 1.3, 95% CI: 0.8, 2.1); at-risk overweight, Q2 (OR: 2.0, 95% CI: 1.3, 3.2); Q3 (OR: 2.0, 95% CI: 1.2, 3.2); Q4 (OR: 1.8, 95% CI: 1.1, 2.8); overweight, Q2 (OR: 2.1, 95% CI: 1.3, 3.4); Q3 (OR: 2.2, 95% CI: 1.4, 3.7); Q4 (OR: 1.8, 95% CI: 1.1, 2.9) <sup>1,3</sup>

(Continued)

TABLE 2 (Continued)

<sup>1</sup> OR, odds ratio; Q, quartile; WIC, Special Supplemental Food Program for Women, Infants, and Children.
<sup>2</sup> $\bar{x} \pm \text{SD}$ (all such values unless indicated otherwise).
<sup>3</sup> BMI values based on baseline data presented by Berkey et al (98).
<sup>4</sup> $\beta$ represents the 1-y change in BMI per usual daily serving of each beverage during the same year.
<sup>5</sup> Values were not adjusted for energy; all beverages were included simultaneously in each sex-specific mixed model adjusted for age, Tanner stage, race, menarche (girls), prior BMI z score, height growth, milk type, physical activity, and inactivity. After adjustment for energy, associations were no longer significant: boys, $P > 0.31$ ; girls, $P > 0.15$ .
<sup>6</sup> Data from written communication from Blum.
<sup>7</sup> $\beta$ represents the change in weight (lb) over the 2-y period associated with an increase of 1 serving of soda per week (1 serving = 12 oz).
<sup>8</sup> Increase in BMI and frequency of obesity for each additional daily serving of sugar-sweetened drink consumed after adjustment for anthropometric, demographic, dietary, and lifestyle variables and total energy.
<sup>9</sup> $\beta$ represents the unit change in BMI z score associated with each incremental increase in quartile of percentage of calories from soda, adjusted for age at menarche, parental overweight, and servings of fruit and vegetables.
<sup>10</sup> BMI presented by change in frequency of soft drink consumption from 1991 to 1995. Categories: a) consistent $\leq 1/\text{wk}$ , b) consistent $\geq 1/\text{d}$ , and c) $\leq 1/\text{wk}$ to $\geq 1/\text{d}$ , and d) $\geq 1/\text{d}$ to $\leq 1/\text{wk}$ .
<sup>11</sup> Greater increase in weight and BMI shown in females who increased soft-drink consumption from $\leq 1/\text{wk}$ to $\geq 1/\text{d}$ than in those who were consistent $\leq 1/\text{wk}$ , consistent $\geq 1/\text{d}$ , or $\geq 1/\text{d}$ to $\leq 1/\text{wk}$ .
<sup>12</sup> Normal weight or underweight defined as BMI $< 85$ th percentile, overweight defined as BMI $85$ th– $< 95$ th percentile, and overweight defined as BMI $\geq 95$ th percentile according to the Centers for Disease Control and Prevention growth chart.
<sup>13</sup> Referent quartile of sugar-sweetened drink consumption: quartile 1 (0 to $< 1$ drink/d), quartile 2 (1 to $< 2$ drinks/d), quartile 3 (2 to $< 3$ drinks/d), and quartile 4 ( $\geq 3$ drinks/d).

**TABLE 3**  
Experimental trials and intervention<sup>y</sup>

Reference	Population	Baseline age or age range	Design	Intervention and main outcome measures	Duration	BMI		Results
						Baseline	Endpoint	
DiMeglio et al (44)	15 Adults (8 female, 7 male)	22.8 ± 2.73 <sup>2</sup>	Crossover	Isocaloric liquid (soda) vs solid (jelly beans) load and body weight and appetite control	2 × 4 wk, 4-wk washout	Liquid, 21.8 ± 2.2; 22.1 ± 2.3	Liquid, 21.9 ± 2.1; solid, 22.2 ± 2.2	Significant increase in body weight and BMI after liquid load ( <i>P</i> < 0.05)
Ebbeling et al (48)	103 Adolescents (56 female, 47 male)	13–18	Randomized controlled trial	Weekly home delivery of noncaloric beverages (4 servings/d for subjects) and telephone contact	25 wk	Intervention, 25.7 ± 6.3; control, 24.9 ± 5.7	Change in BMI: intervention, 0.07 ± 0.14; control, 0.21 ± 0.15 <sup>3</sup>	Decreasing sugar-sweetened beverage intake significantly reduced body weight in subjects with baseline BMI >30 (net BMI change = 0.75 ± 0.34 in treatment group compared with control subjects in the upper baseline BMI tertile)
James et al (45)	644 Children (29 clusters)	7–11	Cluster randomized controlled trial	Focused educational program on nutrition (15 intervention clusters and 14 control clusters) and drink consumption and weight status	One school year	Intervention, 17.4 ± 0.6; control, 17.6 ± 0.7	Intervention, 17.9 ± 0.7; control, 17.4 ± 0.6	Greater percentage of obesity and overweight in control subjects than in the intervention group (mean difference, 7.7%; 95% CI: 2.2%, 13.1%) and greater consumption of carbonated drinks in control subjects (mean difference, 0.7; 95% CI: 0.1, 1.3)
Raben et al (46)	41 Adults (35 female, 6 male)	20–50	Parallel	Daily supplements of sucrose or artificial sweeteners and effect on appetite and body weight <sup>4</sup>	10 wk	Sucrose, 28.0 ± 0.5; sweetener, 27.6 ± 0.5 <sup>3</sup>	Not given	Body weight, fat mass, and BMI increased in sucrose group and decreased in sweetener group; respective difference between groups (2.6 kg; 95% CI: 1.3, 3.8; 1.6 kg; 95% CI: 0.4, 2.8; and BMI 0.9, 95% CI: 0.5, 1.4)
Tordoff and Allegra (47)	30 Adults (9 female and 21 male)	Female, 28.2 ± 2.7; male, 22.9 ± 0.8 <sup>3</sup>	Crossover	1150 g Soda/d sweetened, with APM compared with HFCS or no soda; assessment of body weight and appetite control	3 × 3 wk	Females, 69.6 ± 4.3 kg; males, 76.6 ± 2.1 kg	Not given	Relative to no soda, HFCS soda significantly ( <i>P</i> < 0.01) increased weight in females (0.97 ± 0.25 kg) and NS increase in males; APM soda decreased weight in males (0.25 ± 0.29 kg, <i>P</i> < 0.05) and NS increase in females

<sup>1</sup> APM, aspartame; HFCS, high-fructose corn syrup; NS, nonsignificant.

<sup>2</sup>  $\bar{x} \pm SD$  (all such values unless indicated otherwise).

<sup>3</sup>  $\bar{x} \pm SE$ .

<sup>4</sup> 70% of sucrose came from beverages, and beverages consisted of several soft drinks and flavored fruit juices.

support the hypothesis that intake of sugar-sweetened beverages is positively associated with weight gain and obesity. Investigations by Raben et al (46) and Tordoff and Alleva (47) compared the effects of the consumption of sucrose and high-fructose corn syrup, a sweetener used to flavor soda, with the consumption of artificial sweeteners on energy intake and body weight. The findings of the study by Raben et al indicate that, in overweight men and women randomly assigned to receive either daily supplements of sucrose or artificial sweeteners for 10 wk, body weight and fat mass increased in the sucrose group (by 1.6 and 1.3 kg, respectively) and decreased in the sweetener group (by 1.0 and 0.3 kg, respectively). Differences between groups were significant for body weight ( $P < 0.001$ ) and fat mass ( $P < 0.01$ ). Tordoff and Alleva (47) observed similar findings when they gave normal-weight subjects 1150 g soda/d sweetened with aspartame (APM) or HFCS or no soda for 3 wk in a  $3 \times 3$  crossover study. To investigate whether sweetened beverages contribute an increased proportion of energy to the diet by eliciting a weak compensatory dietary response resulting in a positive energy balance and weight gain, DiMeglio and Mattes (44) conducted a  $2 \times 4$ -wk crossover trial. Subjects were given 1883 kJ/d of carbohydrate loads in either liquid (soda) or solid (jelly beans) form. The percentage of dietary energy compensation was calculated as  $[(\text{baseline intake} + 1883 \text{ kJ}) - (\text{free-feeding intake} + 1883 \text{ kJ}) / 1883 \text{ kJ}] \times 100$ . During the solid phase, subjects compensated for the energy that was provided by reducing free-feeding intake so that the overall dietary compensation score was precise (118%). However, in the liquid phase, no compensation was observed, and, in fact, total daily energy intake from free feeding increased relative to baseline, which resulted in a dietary compensation score of  $-17\%$  [ie, the energy from the carbohydrate load was added to the customary diet which also increased slightly (17%)]. Consequently, body weight and BMI increased significantly ( $P < 0.05$ ) from pretreatment values only during the liquid phase.

In a recent cluster-randomized controlled trial (RCT) in schoolchildren, James et al (45) found that a school-based educational program aimed at reducing the consumption of carbonated drinks was successful in producing a modest reduction, which was associated with a reduction in the prevalence of overweight and obesity (at 12 mo, the proportion of overweight and obese children in the control group increased by 7.5%, whereas that in the intervention group decreased by 0.2%). More recently, Ebbeling et al (48) conducted a pilot RCT for 25 wk in 103 adolescents aged 13–18 y who regularly consumed sugar-sweetened beverages ( $\geq 1$  serving/d) to evaluate the effects on body weight of decreasing sugar-sweetened beverage consumption. Participants were randomly assigned to either the intervention group, who received weekly home deliveries of noncaloric beverages for 25 wk, or the control group, who continued their usual beverage consumption habits throughout follow-up. Consumption of sugar-sweetened beverages decreased by 82% in the intervention group and did not change in the control group. Decreasing sugar-sweetened beverage consumption had a beneficial effect on body weight that was associated with baseline BMI (the difference in BMI between the treatment group and the control subjects in the uppermost tertile of baseline BMI was  $0.75 \pm 0.34$ ) (48).

## DISCUSSION

Thirty studies were identified and included in this systematic review. Of these, 15 were cross-sectional, 10 were prospective

cohorts, and 5 were experimental. Most of the cross-sectional studies, especially the large ones, found a positive association between the consumption of sugar-sweetened beverages and body weight. Three prospective studies that included repeated measures of both soft drinks and weight found that an increase in the consumption of sugary soft drinks was significantly associated with greater weight gain and greater risk of obesity over time in both children (25, 38) and adults (41). A 1-y intervention study found that reducing soft-drink consumption in schoolchildren led to a significant reduction in the prevalence of overweight and obesity (45), and a 25-week RCT in adolescents found that a reduction in the intake of sugar-sweetened beverages had a beneficial effect on body weight that was strongly associated with baseline BMI (48). Despite our overall findings of a positive association between sugar-sweetened beverage consumption and weight gain and obesity, other investigators have suggested that such a relation does not exist. Multiple studies based on the Continuing Survey of Food Intake for Individuals (CSFII) 1994–1996 (26) and 1998 (27) and NHANES III (1988–1994; 49) did not find significant associations between consumption of soda or fruit drinks and BMI in American children and adolescents. However, data from both surveys suggest a slight positive association between soda consumption and BMI and a slight inverse association between fruit drink consumption and BMI (26, 27). Interpretation of these findings is limited, however, by the fact that they were cross-sectional and relatively small and were conducted in children and adolescents, groups in whom dietary assessment and weight measurement are difficult. A recent risk analysis using CSFII, NHANES III, and National Family Opinion (NFO) WorldGroup Share of Intake Panel (SIP) data evaluated the relation between beverage consumption from school vending machines and adolescent overweight. Findings from the risk assessment showed that removal from the schools of vending machines containing carbonated soft drinks had no effect on BMI (50). As discussed by those authors, it is possible that the removal of vending machines did not affect BMI because soft drink consumption from school vending machines is a small fraction of total soft drink consumption, and the relation between soft drink consumption and BMI is not strong in the study population (50).

Overall, results from our review support a link between the consumption of sugar-sweetened beverages and the risks of overweight and obesity. However, interpretation of the published studies is complicated by several method-related issues, including small sample sizes, short duration of follow-up, lack of repeated measures in dietary exposures and outcomes, and confounding by other diet and lifestyle factors.

## Sample size and duration of follow-up

The discrepancies seen among cross-sectional and prospective cohort studies may relate to study design, sample size, and duration of follow-up. The cross-sectional studies included here vary markedly in size. Only cross-sectional investigations by Berkey (25) and Troiano et al (21) included  $> 10\,000$  children, which may provide sufficient power to effectively assess the relation between the consumption of sugar-sweetened beverages and weight. Sample size and the duration of follow-up of prospective cohort studies also tended to vary. The largest prospective study conducted in children, that of Berkey et al (25), found significant associations between the intake of sugar-sweetened beverages and weight gain in 11 654 children followed for 3 y. The study by Blum et al (36), which found a nonsignificant



association between the intake of sugar-sweetened beverages and year 2 BMI *z* scores included only 166 children, which may have limited the statistical power to predict associations between beverage consumption and BMI. Newby et al (39) also found a nonsignificant association between soda consumption and annual change in BMI in a sample of 1345 children. It is possible that the 6- to 12-mo follow-up in that study was not sufficient and that the participants were too young for a study of the relation between beverage consumption and weight. A small study (not included in Table 2) of 21 children and with a follow-up of 4–8 wk found that the children with the greatest consumption of sweetened beverages (>16 oz/d) gained more weight ( $1.12 \pm 0.7$  kg) than did the children who consumed an average of 6–16 oz sweetened beverage/d ( $0.32\text{--}0.48 \pm 0.4$  kg) (51). Unfortunately, the sample size was too small and the follow-up was too short to provide sufficient power for the observed difference in weight gain to be significant ( $P = 0.4$ ). Two of the 4 studies conducted in adults had 8-y follow-up. Schulze et al (41) studied > 51 000 women and found a significant positive association between soda consumption and weight gain. Kvaavik et al (37) found nonsignificant positive associations between soda consumption and overweight in men and women and between soda consumption and obesity in men. However, their small overall sample size ( $n = 422$ ) and the subsequent stratification of subjects for subgroup analysis may have limited the power of the study to detect significant differences between groups.

#### Dietary assessment methods

The dietary assessment methods used to evaluate beverage consumption are also an important consideration, because each method has its own set of intrinsic errors that could be manifested in effect estimates. In addition, because the relation between beverage intake and weight is longitudinal, a tool that can assess long-term patterns in intake over time, such as an FFQ, would be most appropriate (52). Methods used to assess beverage consumption among the cross-sectional studies are diverse. The 2 largest investigations, those of Berkey et al (25) and Troiano et al (21), employed validated FFQs to assess the previous year's intake and 24-h diet recalls, respectively. Of the 6 prospective cohort studies conducted in children and adolescents, 5 used previously validated FFQs to assess beverage consumption. Studies by Ludwig et al (38), Newby et al (39), and Welsh et al (42) used instruments that evaluated intake over the previous 30 d, and studies by Berkey et al (25) and Phillips et al (40) used instruments that evaluated intake over the previous year. Blum et al (36) used 24-h diet recalls at baseline and study exit (year 2) to assess beverage consumption, which may have further limited the power of the study to detect associations between beverage consumption and BMI. Three of the prospective cohort studies conducted in adults used validated FFQs to assess beverage consumption over the previous year (37, 41, 43), although Kvaavik et al (37) had used 2 different surveys during follow-up before incorporation of the FFQ, which could have led to some degree of misclassification of beverage consumption and attenuation of actual effects. French et al (28) used a short (18-item) FFQ that was constructed specifically for the study; the use of a more comprehensive instrument was not feasible because of the limited time available for subjects to complete questionnaires at the worksites. Omission of certain food items commonly consumed with soda (or sweetened beverages) could affect the reporting of beverage consumption and the ability to control for confounding.

#### Repeated measures

The most comprehensive evaluation of diet and weight involve repeated measurements of both diet and weight over time so that specific changes in diet can be paralleled with changes in weight. Of the 6 prospective cohort studies conducted in children and adolescents, only those by Ludwig et al (38) and Berkey et al (25) reported changes in both the consumption of sugar-sweetened beverages and BMI. Schulze et al (41) evaluated mean changes in weight and BMI in adults according to changes in soda consumption over two 4-y periods and found that weight gain was greatest in women who increased their soda consumption from  $\leq 1/\text{wk}$  to  $\geq 1/\text{d}$  and smallest in women who decreased their intake.

Ascertainment of repeated measures of diet and weight allows for tracking and identification of particular dietary items that elicit changes in weight. Whereas repeated measures of diet and weight are useful for characterizing longitudinal relations, it is important to acknowledge that longitudinal analyses are not immune to the problem of reverse causation (ie, persons change their diet because of their weight) that commonly plagues cross-sectional analysis, because longitudinal analyses typically compare changes in one variable with changes in another. Stable intake patterns over time, on the other hand, may be more informative because the direction of association would be clearer, although the follow-up required for such analyses must be sufficiently long for measures of stable intake over time to be evaluated.

#### Confounding

The cross-sectional studies included in this review are particularly prone to confounding, because beverage consumption and weight were measured at only one timepoint. For example, overweight persons may abstain from consuming soda or switch to diet soda as part of a weight-loss strategy, which could result in a spuriously negative association or underestimation of the link between overweight and soda consumption. Despite these limitations, cross-sectional studies are important for hypothesis generation, and they provide an impetus for conducting prospective cohort and experimental investigations (52). Although prospective cohort studies are better able to control for confounding than are cross-sectional studies, they still are observational in nature and may not completely disentangle the effects of other aspects of diet and lifestyle from the effects of soda consumption on weight. Many studies have suggested that unhealthy lifestyle behaviors tend to cluster (37, 53–57). Confounding of the association between the intake of sugar-sweetened beverages and weight is difficult to assess in studies conducted in children and adolescents, because their lifestyle patterns are still being developed (58, 59). Two of the 4 prospective cohort studies conducted in adults found that subjects with higher intakes of soda tended to smoke more, be less physically active, and have higher intakes of total energy than did subjects with smaller intakes. In addition, Schulze et al (41) reported higher intakes of total carbohydrate, sucrose, and fructose and an overall higher dietary glycemic load (GL) in subjects with higher soda consumption than in those with lower soda consumption, which could reflect consumption of soda itself or a combination of soda and processed foods commonly consumed alongside soda. Consequently, it is difficult to ascertain whether the weight gain that resulted from the consumption of calories in soda itself or of calories in foods often eaten in conjunction with soda or from a lack of physical activity was counteracted by the weight-reducing effect of smoking.



Therefore, it is important to control for detailed measures of confounding variables. For example, in addition to control for baseline weight, smoking, and alcohol use, Schulze et al (41) controlled for baseline and changes in physical activity and other lifestyle covariates and for the intake of red meat, french fries, processed meat, sweets, and snacks (food items that cluster together in this study population to a “Western” dietary pattern). It is interesting that the study by Bes-Rastrollo et al (43) found that adjustment for total energy intake, snack foods, and other potential confounders did not materially change effect estimates, which suggested that the association between sugar-sweetened beverage consumption and weight is independent of the influence of other foods that were evaluated in multivariate models.

### Biologic mechanisms

Experimental studies are known to provide some of the most rigorous evaluations of dietary intake and body weight. Dietary trials of long duration, although theoretically ideal, can be complicated by high cost and lack of compliance on the part of study participants. However, findings from short-term feeding trials provide valuable insight into possible mechanisms that can explain why the consumption of sugar-sweetened beverages may lead to weight gain and obesity.

The prevailing evidence suggests that weight gain arises because compensation at subsequent meals for energy consumed in the form of a liquid could be less complete than that for energy consumed in the form of a solid, most likely because of the low satiety of liquid foods (20). For example, DiMaggio and Mattes (44) showed that consumption of 1180 kJ soda/d resulted in significantly greater weight gain than did consumption of an isocaloric solid carbohydrate load. Others have reported similar findings (60, 61). Many studies have shown a connection between consumption of sugar-sweetened beverages and total energy intake, which supports the notion that, when persons increase liquid carbohydrate consumption, they do not concomitantly reduce their solid food consumption (9, 11, 21, 25, 35, 37, 39, 62–67). For example, Schulze et al (41) reported that women who increased their intake of sugar-sweetened beverages also increased their total caloric consumption by an average of 358 kcal/d and that most of the excess calories were contributed by soda.

Comparison of beverages sweetened artificially with those sweetened calorically had similar findings. Tordoff and Alleva (47) showed that, in comparison to the values found when subjects received no beverages, total energy intake and body weight increased when those subjects were given 2215 kJ HFCS-sweetened beverage/d for 3 wk but decreased when they were given artificially sweetened carbonated beverage for the same period. Similarly, Raben (46) showed that the consumption of sucrose-containing beverages resulted in greater energy consumption and weight gain over 10 wk than did consumption of artificially sweetened beverages, with most of the exceeding energy intake accounted for by the sucrose supplement; this suggests that subjects consuming calorically sweetened beverages did not compensate for this consumption by reducing the intake of other items, and thus they gained weight (16, 46). Similar results have been reported in preschool children (68). These findings are also supported by the observation in some prospective cohort studies that the consumption of diet soda is negatively associated with energy intake and weight, whereas the intake of sugar-sweetened beverages is positively associated with energy intake and weight (38, 41). However, others have

reported contrary findings (25–27, 37). Evaluation of the consumption of diet soda, energy intake, and weight is complex, because, for some, the consumption of calorie-reduced beverages could serve as justification for consumption of excess calories from other food sources.

Studies evaluating the effects of caloric and noncaloric sweet drinks on hunger and appetite have had conflicting results. Some experimental studies found that the consumption of noncaloric sweeteners does not increase hunger and food intake, whereas the consumption of caloric sweeteners, as speculated, does do so, which implies that participants did not compensate for the energy deficit resulting from the consumption of noncaloric sweeteners in place of caloric sweeteners (69–71). These studies also showed that the consumption of calorically sweetened drinks resulted in greater energy intake than did the consumption of artificially sweetened drinks. Conversely, others have found that replacing calorically sweetened drinks with artificially sweetened drinks did not affect total energy intake and may actually have increased subsequent energy intake (72, 73). These studies also showed that appetite and hunger ratings did not differ according to the type of sweetener consumed and that participants compensated for the energy deficit resulting from the replacement of caloric sweeteners with artificial sweeteners. In addition, some evidence suggests that the palatability of both sugar-sweetened and artificially sweetened drinks increases subjective hunger and hence energy intake and weight gain. However, these findings require further elucidation (41, 44, 74–76).

A recent study conducted in mice suggested that the consumption of fructose-sweetened beverages increases adiposity more than does the consumption of either sucrose-sweetened or artificially sweetened beverages (77). The likely mechanism is believed to be a shift of substrate use to lipogenesis. This finding is of particular interest because soft drinks are sweetened with HFCS in the United States and with sucrose in Europe; it should be noted that fructose and HFCS are not interchangeable, however, because HFCS also contains a glucose fraction. It has been hypothesized that fructose may lead to greater weight gain and insulin resistance by elevating plasma triacylglycerols and subsequently decreasing the production of insulin and leptin in peripheral tissues—not suppressing ghrelin—thereby decreasing signaling to the central nervous system from insulin and leptin—and possibly ghrelin (78–81). However, the sugar composition (ie, the amount of glucose compared with that of fructose) of HFCS and sucrose, which contain the same number of calories, does not differ appreciably. Whether HFCS is more detrimental to weight gain than are other types of sugar requires further study.

### Diabetes and other health consequences

In addition to its potential role in weight gain, the intake of sugar-sweetened soda may increase the risk of type 2 diabetes. Schulze et al (41) observed that the intake of soft drinks, rather than of fruit juices, was significantly associated with an increased risk of diabetes, even after adjustment for BMI. This association likely is mediated in part through the high amount of rapidly absorbable carbohydrates such as HFCS that are found in soda in the United States, and the absorbability of those carbohydrates has an effect on blood glucose similar to that of sucrose (82). Although sugar-sweetened beverages on average have a moderate glycemic index (83), they have been shown to contribute to a high glycemic load (GL) of the overall diet by virtue of the large



quantities consumed; this high GL is associated with poor glycemic control, particularly among persons with diabetes (84, 85). Several studies also suggested that inflammatory biomarkers such as C-reactive protein (86, 87) and haptoglobin (88, 89) may be associated with the risk of diabetes and may be compounded by the intake of rapidly digested and absorbed carbohydrates (86). A recent study investigating the effect of sucrose-sweetened and artificially sweetened food and drinks on inflammatory markers in overweight subjects found that consumption of sucrose-sweetened items significantly increased plasma haptoglobin and transferrin but nonsignificantly increased C-reactive protein (90). This study corroborates findings from others that suggest that the proinflammatory process underlying the greater risk of diabetes may be exacerbated by a high intake of rapidly digested and absorbed carbohydrates (90).

It has also been suggested that soft drinks that contain caramel coloring are rich in advanced glycation end-products, which may increase insulin resistance and inflammation: however, such findings were not reported for diet soda and warrant further investigation (91, 92). Recent findings from a prospective cohort study also indicated that the intake of sweetened soft drinks may be associated with a greater risk of pancreatic cancer, particularly in women with high BMI or a low physical activity level and an underlying degree of insulin resistance (93).

The consumption of soft drinks has also been linked to other health consequences, which are apparent to the greatest degree in children and adolescents. Savoca et al (94) found that the intake of caffeine from soda (10–16 mg/100 g) may increase blood pressure in adolescents, especially those of African American background, thereby increasing their risk of hypertension, although this adolescent population's blood pressure may also be affected by dietary and lifestyle practices for which the consumption of caffeinated beverages is a marker. Additional research is therefore warranted, particularly because the incidence of adolescent hypertension is on the rise (95, 96). Recent findings suggest that regular coffee consumption may reduce the risk of diabetes (97). However, the benefits of coffee are most likely due to components of coffee, such as chlorogenic acid and magnesium, other than caffeine, because both caffeinated coffee and decaffeinated coffee have been found to lower risk of diabetes.

Additional implications of sugar-sweetened beverage consumption, particularly in children and adolescents, include the displacement of milk and other more nutritious beverages from the diet (11, 15, 33, 35, 36, 66, 67, 98, 99). Reduction of milk intake among children is a public health concern because milk is an important source of protein and of certain vitamins and minerals, such as calcium, vitamin D, vitamin A, and vitamins B-12 and B-6, and some survey data have indicated that the intake of calcium by children and adolescents is declining in the United States (15). In contrast to these findings, others have suggested that the consumption of added sugars such as soda and fruit drinks has a negligible effect on overall diet quality (100). Several studies showed that the consumption of cola-type beverages in particular is negatively associated with bone mineral density and positively associated with bone fractures (101–104). These findings are believed to be mediated by the high phosphate content of cola, which leads to a change in the calcium-phosphorus ratio in the diet and ultimately to a deleterious effect on bone (102). Low calcium intake during adolescence is critical because it jeopardizes the accrual of maximal peak bone mass. It has been suggested that a 5–10% deficit in peak bone mass may result in

a 50% greater lifetime prevalence of hip fracture (102). Contrary to these findings, a study conducted among CSFII participants suggested that the consumption of soda, fruit drinks, and other nondairy beverages is positively, although weakly, associated with calcium intake (105). Furthermore, the intake of soft drinks has been linked to increased risk of dental caries because of the sodas' high sugar content and acidity, which result in enamel erosion over time (106), although data from NHANES III suggest that carbonated soft drinks are not associated with poor dental health (107).

### Fruit juices

Although the focus of this review is soda and other nonnutritive sugar-added beverages such as fruit drinks, fruit juices such as apple juice, which are consumed in great quantities by young children, have also been linked to overweight and obesity by some investigators. In a population-based cross-sectional study by Dennison et al (108), the prevalence of overweight was higher in those children aged 2–5 y who were consuming  $\geq 12$  fluid oz juice/d than in those drinking  $< 12$  fl oz juice/d (32% of children drinking  $\geq 12$  fl oz fruit juice/d and 9% of those drinking  $< 12$  fl oz/d had a BMI  $\geq 90$ th age- and sex-specific percentile;  $P < 0.01$ ). Similar findings were reported by others (109). In a later study by Dennison (110), it was suggested that previously reported associations between high intakes of fruit juice and obesity were observed with apple juice only, which likely reflects the high fructose (13.9 g/8 oz serving) and sucrose (4.2 g/serving) content of apple juice (111). However, others who studied juice intake longitudinally found that the consumption of fruit juice, irrespective of type, does not influence weight (112, 113). A recent prospective cohort of adults in a Mediterranean population found a weak but significant association between weight gain and sweetened fruit juice consumption [OR: 1.16; 95% CI: 0.99, 1.36 (43)]. Further evaluation of the effect on weight of fruit juice intake in general and by type is warranted because fruit juice remains an important source of vitamins and minerals, particularly for children.

### Conclusions

The consumption of sugar-sweetened beverages has increased dramatically in the past decades, in parallel with increasing prevalences of overweight and obesity in the United States. Currently, sugary soft drinks contribute  $\approx 8\%$ – $9\%$  of total energy intake in both children and adults (15). Although it has long been suspected that soft drinks contribute at least in part to the obesity epidemic, only in recent years have large epidemiologic studies begun to investigate the relation between soft-drink consumption and long-term weight gain.

In this systematic review, findings from several large cross-sectional investigations, well-powered prospective cohort studies with long follow-up and repeated measures of diet and weight, a school-based intervention targeting soda consumption, and an RCT assessing the effect of reducing sweetened beverage consumption have provided strong evidence for the independent role of the intake of sugar-sweetened beverages, particularly soda, in the promotion of weight gain and obesity in children and adolescents. Findings from prospective cohort studies conducted in adults, taken in conjunction with results from short-term feeding trials, also support a positive association between soda consumption and weight gain, obesity, or both. However, further research,



particularly from large prospective cohort studies with long follow-up and repeated measures of both diet and weight, is needed to provide more convergence in the data. Experimental studies have suggested that the likely mechanism by which sugar-sweetened beverages may lead to weight gain is the low satiety of liquid carbohydrates and the resulting incomplete compensation of energy at subsequent meals. It has also been suggested that the HFCS content of soda may have a particular role in adiposity and diabetes risk, although further experimental research is needed to fully elucidate the detrimental effects of HFCS in comparison with those of other types of sugars.

Sugar-sweetened beverages, particularly soda, provide little nutritional benefit and increase weight gain and probably the risk of diabetes, fractures, and dental caries. Given that global incidence rates of overweight and obesity are on the rise, particularly among children and adolescents, it is imperative that current public health strategies include education about beverage intake. Consumption of sugar-sweetened beverages such as soda and fruit drinks should be discouraged, and efforts to promote the consumption of other beverages such as water, low-fat milk, and small quantities of fruit juice should be made a priority. 

FBH conceived the idea for this study. VSM and MBS extracted the data. VSM and FBH wrote the manuscript. VSM, MBS, and FBH interpreted the data and edited the final draft of the manuscript. None of the authors had a personal or financial conflict of interest.

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