Sugar-sweetened beverages and body mass index in children and adolescents: a meta-analysis[1–4]

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ABSTRACT

Background: Rates of overweight and obesity have increased. Consumption of sugar-sweetened beverages (SBs) may play a role.

Objective: The purpose of this meta-analysis was to determine whether the results of original research with the use of longitudinal and randomized controlled trials (RCTs) support the hypothesis that SB consumption is associated with weight gain among children and adolescents.

Design: The MEDLINE database was used to retrieve all original studies of SBs and weight gain involving children and adolescents. Twelve (10 longitudinal and 2 RCT) studies were reviewed. Eight of the longitudinal studies and both RCT studies were incorporated into a quantitative meta-analysis. Forest plots and overall estimates and CIs for the association of the difference (Δ) in SB consumption with Δbody mass index (BMI; in kg/m^2) were produced. Funnel plots were examined as a diagnostic test for publication bias. Databases of unpublished scientific studies were searched. Sensitivity tests were conducted to examine the robustness of the meta-analysis results.

Results: The overall estimate of the association was a 0.004 (95% CI: −0.006, 0.014) change in BMI during the time period defined by the study for each serving per day change in SB consumption with the fixed-effects model and 0.017 (95% CI: −0.009, 0.044) with the random-effects model. The funnel plot is consistent with publication bias against studies that do not report statistically significant findings. The sensitivity tests suggest that the results are robust to alternative assumptions and new studies.

Conclusion: The quantitative meta-analysis and qualitative review found that the association between SB consumption and BMI was near zero, based on the current body of scientific evidence. *Am J Clin Nutr* 2008;87:1662–71.

INTRODUCTION

Rates of overweight and obesity have increased nationally and globally (1). The causes of obesity are numerous and complex; involving genetic, psychological, social, and environmental components (2). The role of sugar-sweetened beverages (SBs) in the development of overweight and obesity has received scientific and policy attention. Several researchers, advocacy groups, and professional groups opine that SB consumption plays an important role in the development of overweight and obesity and warrants special attention as policies are developed to reduce the overweight and obesity rates (3, 4).

The overall effect of SBs on overweight and obesity depends primarily on 2 factors: the current distribution of consumption of SBs and the magnitude of the effect (if any) of SB consumption on body mass index (BMI; in kg/m^2) or other measures of weight status.

In the United States, current average consumption of SBs for adolescents 12-19 y of age are 630 g/d and 409 g/d for males and females, respectively. Average consumption of fruit drinks and ades is 105 g/d and 115 g/d for males and females, respectively. For children 6-11 y of age, average consumption of SBs is 284 g/d for boys and 213 g/d for girls, and the average consumption of fruit drinks and ades is 102 g/d for boys and 96 g/d for girls (5).

The purpose of this meta-analysis was to determine whether the results of original research that used longitudinal and randomized controlled trials (RCTs) support the hypothesis that SB consumption is associated with increased BMI among children and adolescents and, if so, to determine the magnitude of the effect.

SUBJECTS AND METHODS

The MEDLINE database (National Library of Medicine, Bethesda, MD) was used to identify relevant English-language articles published between 1966 and October 2006 about studies of the intake of SBs and BMI, obesity, or both. Sugar-sweetened drinks included soft drinks and fruit drinks or ades. On the basis of guidance from the medical subheading (MeSH) terms database, the following search term combinations were used: "beverages obesity," "beverages BMI," "soft drinks obesity," "soft drinks BMI," "sweetened drinks," and "sugar drink fat mass."

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[2] The authors retained complete control of the study design, collection of data, analysis of data, and interpretation of results. The research proposal to the sponsor was approved as submitted, but the sponsor requested that an independent expert on meta-analysis—to be chosen by the authors—review the manuscript. Courtesy copies of the manuscript were provided to the sponsor at the time of submission, but the sponsor had no editorial control. One author (MLS) accepted a position with the sponsor after the first decision letter regarding the manuscript was received. The data used in the analysis are available to other researchers for replication and extension of the analysis. The views expressed by the authors are their own and may not represent the views of the University of Maryland.

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The searches yielded 127, 70, 22, 67, 112, and 3 articles, respectively.

Selection of core articles was restricted to original research in the English language with human subjects $<$ 19 y of age that examined the association between SBs and weight gain, obesity, or both. Ecologic and cross-sectional designs were excluded. The bibliographies from 5 review articles (6–10) were also checked to ensure that all relevant studies had been captured. A total of 12 (10 longitudinal and 2 RCT) studies were reviewed. Eight of the longitudinal studies and both RCT studies were incorporated into a quantitative meta-analysis. The remaining studies did not provide the necessary information for inclusion in the quantitative meta-analysis, so these studies were reviewed individually.

To minimize possible publication bias, searches were also conducted on databases that contain unpublished scientific studies. Six databases were searched: Computer Retrieval of Information on Scientific Projects, Current Research Information System, Web of Science, ClinicalTrials.gov, BIOSIS Previews, and Proquest Interdisciplinary Dissertations and Theses. E-mail requests for more information were sent to the corresponding author for any eligible study identified in our search of unpublished literature and to any corresponding author whose published study did not provide enough information to be included in the quantitative analysis. An independent expert reviewed an earlier draft of the manuscript and provided constructive criticism and useful advice.

Eight longitudinal (**Table 1**) and 2 RCT studies (**Table 2**) were included in the meta-analysis. Coefficients and standard errors were extracted from the articles and compiled into a statistical database in STATA software, version 9.2 (11). When standard errors were not reported, they were calculated by us, based on reported CIs or *P* values. The results were analyzed with the use of METAN: STATA module for fixed- and random-effects meta-analysis program (12). METAFUNNEL: Stata module to produce funnel plots for meta-analysis (13) was used to produce funnel plots to assess the potential for publication bias. METANINF: Stata module to evaluate influence of a single study in meta-analysis estimation (14) was used to test for particularly influential studies. Sensitivity tests were conducted to assess the extent to which assumptions used in the meta-analysis or future research findings could affect the results. The databases and Stata command files used for the analysis are available in a digital repository for other researchers to review and replicate (*see* Supplemental Data in the current online issue).

For some studies it was necessary to apply scaling factors to express the results in terms of the change (Δ) in BMI units per 12-oz serving ΔSB. One study defined a serving size as 100 g instead of the more typical 370-g (12-oz) serving size (15), and another used 1-oz units in the analysis (16). For consistency, the coefficient and SE for those studies were scaled by factors of 3.7 and 12, respectively, to make them consistent in serving size with other studies. When results were presented in weight change, the effect size was divided by the square of the average height in meters for respondents in the study.

Forest plots show the estimated effect size, CI, and the precision of each study in the meta-analysis. Forest plots were generated, and overall estimates of the pooled relation and SE were calculated with the use of both fixed-effects and random-effects models. Fixed-effects models assume that a single common effect underlies all of the studies in the meta-analysis. Random-effects models assume that not all studies in the analysis are estimating the same underlying common effect. Test statistics indicated heterogeneity in the results from the studies included in the meta-analysis, so the random-effects estimates are more appropriate.

RESULTS

Quantitative meta-analysis of longitudinal studies

Ten longitudinal studies were identified for the review (15–24), and 8 studies were included in the quantitative analysis (15–18, 20–23). Four of those studies used ΔBMI as the outcome variable and ΔSB consumption as the key independent variable. Two of those studies reported separate, independent models for males and females and are consequently included twice in the meta-analysis forest plot (16, 17). One longitudinal study used the change in fat mass as the outcome variable and SB consumption as an independent variable in a multilevel random-effects model (16). The study reported no statistically significant association between SB consumption and fat mass development. The effect size and SE for fat mass development was converted to ΔBMI units with the use of an average height of 1.6 m for females and 1.7 m for males. Blum et al (18) reported that they did not find a statistically significant association between SB and BMI *z* score in a 2-y study of 166 school-age children. The coefficient was not reported in the original article, but a review reported that the coefficient was -0.003 with an SE of 0.004 (9). These statistics were converted to ΔBMI units with the use of the L-M-S method. A longitudinal study used BMI *z* score as the outcome variable and SB consumption as the independent variable in a linear mixed-effects model (23). That study found a positive association between SB consumption and BMI *z* score. BMI *z* score was converted to ΔBMI with the use of the L-M-S method. Finally, a longitudinal study of 21 subjects used Δkilogram as the outcome variable (21). The Δkilogram was converted to ΔBMI by dividing by the average height in meters squared of the subjects.

Randomized controlled trial studies

We identified 2 RCT studies that met our criteria (25, 26). For the purpose of the quantitative meta-analysis we extracted the estimated difference and SE between the intervention group and the control group. None of the RCT studies found a statistically significant difference between the treatment and control groups. The estimated differences in BMI ranged from 0.1 to 0.14.

Viewed graphically, the studies with the most weight showed remarkably similar results (**Figure 1**). All of the studies with $>$5% weight had effect sizes near zero, and all had relatively precise estimates because of the large sample sizes used in the studies. The estimated associations between ΔSB consumption and ΔBMI ranged from -0.02 to 0.04 ΔBMI per serving per day among the studies with $>$5% weight. The results from Ludwig et al (20) and Phillips et al (23) stand out from the others. Ludwig et al (20) had the highest estimated association (0.24 ΔBMI/serving per day) and the largest 95% CI of the longitudinal studies. Phillips et al (23) also had a positive, statistically significant estimated association with a relatively large CI.

The overall estimate of the association was a 0.004 change in BMI during the time period defined by the study for each serving per day change in SB consumption with a 95% CIs of -0.006 and 0.014 with the use of the fixed-effects model and 0.017 with a 95% CIs of -0.009 and 0.044 with the use of the

TABLE 1
Review of longitudinal epidemiologic studies on the association between sugar-sweetened beverage (SB) consumption and weight gain

Study	Type of analysis	Summary of results	Remarks
Berkey et al (17)	Longitudinal US Growing Up Today Study (GUTS) Analyzed the relationship between BMI (in kg/m^2) and intakes of sugar-added beverages, milk, fruit juices, and diet soda in a cohort of >10 000 boys and girls aged 9–14 y in 1996.	Positive association between BMI and sugar-added beverage consumption for boys ($P = 0.038$), but the association was not statistically significant for girls ($P = 0.096$). For each serving of sugar-added beverages consumed per day, BMI increased by 0.028 for boys and by 0.021 for girls from the previous year. When total energy was included in the model, the associations were not significant for either boys ($P = 0.317$) or girls ($P = 0.167$).	This study found no statistically significant association between soda consumption and the BMI after control for total energy.
Blum et al (18)	Longitudinal Existing data were reexamined to determine changes in beverage consumption and associations between beverages consumed and the BMI *z* score in children ($n = 164$) across 2 y. Beverages (milk, 100% juice, diet soda, or SB) and total caloric intake were calculated from a 24-h diet recall. Height and weight were measured to calculate BMI. Subjects were categorized by BMI *z* score as normal-weight, overweight, gained weight, and lost weight. Data were collected at baseline and year 2.	Significant decreases in milk and increases in diet soda were found over 2 y in all subjects and normal-weight subjects, whereas overweight subjects had a significant increase in diet soda consumption and a decrease in milk consumption that was not significant. Change in milk consumption was inversely correlated with SB consumption. Increases in diet soda consumption were significantly greater for overweight subjects and subjects who gained weight than for normal-weight subjects. Baseline BMI *z* score and year 2 diet soda consumption predicted 83.1% of the variance in year 2 BMI *z* score.	Diet soda was the only type of beverage associated with year 2 BMI *z* score, and its consumption was greater in overweight subjects and subjects who gained weight than in normal-weight subjects at 2 y.
Ludwig et al (20)	Longitudinal The cohort was 548 ethnically diverse schoolchildren aged 11–12 y enrolled in Massachusetts public schools. Examined the relation between BMI and consumption of sugar-sweetened drinks. Changes in BMI and SB consumption were measured for 19 mo.	Average SB consumption increased from 1.22 to 1.44 servings/d—a difference of 0.22 servings/d. After control for baseline anthropometrics and demographics, dietary variables, physical activity, television viewing, and total energy intake, the estimated association of SBs with BMI was a 0.24 increase in BMI for each additional serving/d increase in SB consumption ($P = 0.03$).	For the average increase in SB consumption (0.22 servings/d), this model predicted an annual BMI increase of 0.05, assuming all other variables in the model remained constant.
Mrdjenovic and Levitsky (21)	Longitudinal Examined the effects of excessive sweetened drink consumption [defined as >12 oz/d (>370 g)/d] on total energy intake and weight gain among 30 children aged 6–13 y attending the Cornell Summer Day Camp in 1997. Three beverage categories were included in the analysis—milk (fluid milk and milk shakes), 100% fruit juice, and sweetened drinks (carbonated fruit-flavored drinks, noncarbonated fruit-flavored drinks, <100% fruit juice, sodas, and tea). Daily beverage consumption was divided into 4 categories—0 [no drink consumed (0 g/d)], 1 [≤6 oz (186 g)], 2 [6–12 oz (186 and 370 g)], 3 [>12 but <16 oz (>370 but <492 g)], and 4 [>16 oz (>492 g)].	Children who consumed >16 oz/d (>492 g/d) of sweetened drinks gained more weight (1.12 ± 0.7 kg) than did children who consumed 6–16 oz/d (186 and 492 g/d) of sweetened drinks (0.32–0.48 ± 0.4 kg). In addition, children who consumed >12 oz/d (>370 g/d) of fruit juice gained more weight (3.3 ± 1.95 kg) than did children who consumed <6 oz/d (<186 g/d) of fruit juice (0.5 ± 0.4 kg). None of these differences was statistically significant, and the investigators observed that "the sample size was too small ($n = 21$) to provide sufficient power for the observed difference in weight gain to be statistically significant" (56).	

(*Continued*)

TABLE 1 (*Continued*)

Study	Type of analysis	Summary of results	Remarks
	Daily dietary intakes were collected over 4–8 wk. Body weights and heights were measured either after the first week of camp or on the first day the child joined the study. Second weight measurements were recorded during a child's final week at camp and were not obtained for all study participants ($n = 21$).		
Mundt et al (16)	Longitudinal Study examined whether a significant relation exists between fat mass (FM) development and physical activity (PA) or SB consumption in healthy boys and girls aged 8–19 y. A total of 105 males and 103 females were assessed during childhood and adolescence for a maximum of 7 y and a median of 5 y. Height was measured biannually. Fat-free mass (FFM) and FM were assessed annually by dual-energy X-ray absorptiometry. Energy intake and SB consumption were assessed with a 24-h dietary intake questionnaire completed 2–3 times/y. Multilevel random-effects models were used to test the relation.	With control for maturation, FFM, and energy intake adjusted for SB consumption, PA level was negatively related to FM development in males ($P < 0.05$) but not in females ($P > 0.05$). In contrast, there was no relation between SB consumption and FM development of males or females ($P > 0.05$). There was also no interaction effect between SB consumption and PA ($P >$ 0.05) for FM development.	Male and female participants lived in Canada and had average heights and weight that were similar to Canadian reference norms. However, the energy intakes of this sample were lower in all age groups and both sexes when compared with Canadian averages.
Newby et al (22)	Longitudinal North Dakota Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) Cohort of 1345 children aged 2–5 y visited WIC clinics at least twice between January 1995 and June 1998. Explored the relation between beverage consumption and changes in BMI.	Found no significant relations between any of the beverages analyzed and BMI. When soda was analyzed separately, an increase in soda consumption of 1 oz/d (31 g/d) predicted a nonsignificant decrease of 0.01 ± 0. 02 BMI units/y ($P = 0.50$). When all beverages were included in the model, an increase in soda consumption of 1 oz/d (31 g/d) predicted an identical BMI unit/y decrease ($P =$ 0.58).	This study found no relation between soda consumption and the BMI values of young children.
Phillips et al (23)	Longitudinal Used data from the Massachusetts Institute of Technology Growth and Development Study to examine the longitudinal relation of energy-dense snack (EDS) food intake with relative weight status and percentage body fat (%BF). Nonobese premenarcheal girls 8–12 y of age ($n = 196$) were enrolled between 1990 and 1993 and followed until 4 y after menarche. At each annual follow-up visit, data were collected on %BF, BMI z score, and dietary intake.	At study entry, girls had a mean (± SD) BMI z score of −0.27 ± 0.89, consumed 2.3 ± 1.7 servings of EDS foods/d, and consumed 15.7 ± 8.1% of daily calories from EDS foods. Linear mixed-effects modeling indicated no relation between BMI z score or %BF and total EDS food consumption. Soda was the only EDS food that was significantly related to BMI z score during the 10-y study period, but it was not related to %BF. In addition, a significant positive relation was observed between EDS food consumption and television viewing.	The results suggested a significant relation between percentage of calories from soda and BMI z score. Subjects in the third and fourth quartiles had BMI z scores that were ≈0.17 units higher on average than those of subjects in the first quartile. The study found no significant relation between %BF and soda consumption.

(*Continued*)

TABLE 1 (*Continued*)

Study	Type of analysis	Summary of results	Remarks
Striegel-Moore et al (15)	Longitudinal Examined longitudinal changes in consumption of 6 types of beverages (milk, diet and regular soda, fruit juice, fruit-flavored drinks, and coffee or tea) in girls and determined the relation between beverage intake, BMI, and nutrient intake. Three-day food diaries were included from black (n = 1210) and white (n = 1161) girls who participated in the National Heart, Lung, and Blood Institute Growth and Health Study. Diaries were recorded during annual visits beginning at ages 9 or 10 y until age 19 y. Mixed models estimated the association of *1*) visit and race with average daily consumption of beverages and *2*) beverage intake with BMI and average daily intake of total calories, sucrose, fructose, total sugars, and calcium.	Changes in beverage intake with time varied by race for all beverages except fruit juice. For all beverage categories, consumption was associated with caloric intake. Of all beverage consumption, increasing that of soda predicted the greatest increase in BMI. The estimated association of regular soda consumption and BMI was 0.011/100 g.	The sample was not nationally representative; the models did not control for PA level. The coefficients for soda, fruit juice, fruit drinks, and coffee are all similar (between 0.005 and 0.011), and the CIs for all of the beverages have substantial overlap with one another.

random-effects model. The study by Mrdjenovic and Levitsky (21) was excluded from the forest plot because it had a much larger CI than any other study, but adding the study by Mrdjenovic and Levitsky (21) to the meta-analysis produces exactly the same results.

Qualitative analysis of longitudinal studies

The results of the other longitudinal studies are consistent with the results of the quantitative meta-analysis. They show that, although the association between ΔSB consumption and ΔBMI may be statistically significant in some studies, the magnitude of the association is not large.

Field et al (19) analyzed the Growing Up Today Survey and reported no association between snack food consumption (including SBs) and ΔBMI. The study was not included in the meta-analysis because the study did not estimate the independent association of SBs with ΔBMI. In addition, another study included in the meta-analysis used the same Growing Up Today Survey data set (17). Including 2 studies that used the same data set would be unnecessary and inappropriate.

Welsh et al (24) examined the association between baseline consumption of all sweet drinks (soda, fruit drinks, vitamin C–containing juice, and other juice) and development of overweight among 10 904 low-income children 2-3 y of age. Consumption of sweet drinks was not associated with the risk of overweight for children who were normal or underweight at baseline. A statistically significant association was observed between sweet drink consumption and the risk of overweight for those children who were overweight or at risk of overweight at baseline. The study was not included in the meta-analysis because it did not report the association between SBs and BMI. All of the reported estimates combined SBs with other beverages. The results of these longitudinal studies are consistent with the findings from the meta-analysis.

Publication bias and sensitivity tests

We examined the potential for publication bias and the overall robustness of the meta-analysis with the use of 4 approaches. We analyzed the influence of each individual study on the overall results, performed a funnel plot analysis, searched for relevant studies in databases of unpublished research, and conducted sensitivity tests.

No single study had a large influence on the overall results. The meta-analysis was reestimated, removing one study at a time. The average effect size ranged from a maximum of 0.020 (95% CI: −0.004, 0.043) when the study by Mundt et al (26) (males) was excluded to a minimum of 0.005 (95% CI: −0.012, 0.022) when the study by Phillips et al (23) was excluded in the random-effects model.

One general concern with meta-analysis is publication bias—the set of published studies may not represent the full spectrum of results from published and unpublished studies. For example, published studies may not include some studies that did not report statistically significant findings because there is a tendency to reject studies with results that are not significant. If unpublished studies finding no relation exist, the overall effect size will be closer to zero or have a wider variance than reported in this analysis. Recent articles have suggested that research supported by the food industry may not publish results that show a positive association between SB consumption and BMI (27, 28). To the best of our knowledge, none of the studies included in this meta-analysis received funding from the food industry. If statistically significant results were not published, the overall effect size will be larger than the pooled estimate reported in this analysis.

The funnel plot is a common diagnostic tool to assess publication bias. The studies are plotted with the precision of the study on the vertical axis and the effect size on the horizontal axis. In

TABLE 2
Review of randomized controlled trials (RCTs) of the association between sugar-sweetened beverage (SB) consumption and weight gain

Study	Type of analysis	Summary of results	Remarks
Ebbeling et al (25)	RCT The researchers randomly assigned 103 adolescents aged 13–18 y who regularly consumed SBs to intervention and control groups. The intervention, 25 wk in duration, relied largely on home deliveries of noncaloric beverages to displace SBs and thereby decrease consumption. Change in SB consumption was the main process measure, and change in BMI (in kg/m^2) was the primary endpoint.	All of the randomly assigned subjects completed the study. Consumption of SBs decreased by 82% in the intervention group and did not change in the control group. Change in BMI, adjusted for sex and age, was 0.07 $\pm$ 0.14 ($\bar{x} \pm$ SE) for the intervention group and 0.21 $\pm$ 0.15 for the control group. The net difference, -0.14 ± 0.21, was not significant overall. However, baseline BMI was significant effect modifier. Among the subjects in the upper baseline BMI tertile, BMI change differed significantly between the intervention (-0.63 ± 0.23) and control ($+0.12 \pm 0.26$) groups, a net effect of -0.75 ± 0.34. The interaction between weight change and baseline BMI was not attributable to baseline consumption of SBs.	The net difference was not significant overall but varied considerably over the range of baseline BMI. The intervention effect was significant for baseline BMI > 30. BMI changes did not differ significantly between the intervention and control groups for those who were not in the upper tertile of baseline BMI.
James et al (26)	Cluster RCT Educational intervention program focused on carbonated drink consumption and overweight and obesity in 644 children aged 7–11 y. The children were recruited from 6 primary schools in southwest England and assigned to 1 of the 29 study clusters that were each randomly assigned to the intervention or control group. Children in the intervention clusters participated in a program designed to emphasize the consumption of a balanced healthy diet and to discourage the consumption of both sweetened and unsweetened "fizzy" drinks. Included anthropometric measurements taken at 6-mo intervals and 3-d dietary records (2 weekdays and 1 weekend) were obtained at baseline and at the end of the trial.	Observed a decrease in carbonated drink consumption of 0.6 glasses/3 d (50 mL/d) in the intervention group with an increase in carbonated drink consumption of 0.2 glasses/3 d (17 mL/d) in the control group. Mean percentage of overweight and obese children decreased by 0.2% in the intervention group and increased by 7.5% in the control group. The percentage difference of overweight and obese children between the intervention and control groups was statistically significant (7.7%; 95% CI: 2.2%, 13.1%). Differences in average BMI values (0.1; 95% CI: -0.1, 0.3) and z scores (0.04; 95% CI: -0.04, 0.12) between the intervention and control groups were not statistically significant.	This study examined whether an intervention program could effectively decrease consumption of fizzy drinks. It did not control for variables such as activity level, other dietary intake, and socioeconomic status. It was also subject to other limitations, such as low retention of subjects (36% of the sample returned both surveys), possible contamination because randomization was done by class not by school, and validity of self-collected dietary data.

the absence of publication bias, the funnel plot is expected to show greater dispersion among the less-precise studies at the bottom of the plot, but studies should be distributed in a roughly symmetrical pattern around the average effect size. If the funnel plot is asymmetrical, it suggests that publication bias may be present.

The funnel plot for these studies shows that the studies with precise estimates are tightly and symmetrically grouped around the average effect size (**Figure 2**). The less-precise studies are not symmetrically grouped around the average effect size. None of the less-precise studies showed an effect size less than the average effect size, and many were above the pseudo-95% CI. This is consistent with a bias against publishing studies that do not show statistically significant results. It is not consistent with a bias against publishing studies that show large effect sizes. If studies with nonsignificant or negative findings exist but were not published, the pooled estimates from the meta-analysis will be larger than the true effect.

To further examine the possibility of publication bias, we conducted a search of databases that contain unpublished scientific studies. The databases searched were Computer Retrieval of Information on Scientific Projects, Current Research Information System, Web of Science, ClinicalTrials.gov, BIOSIS Previews, and Proquest Interdisciplinary Dissertations and Theses. We sent an e-mail request to the authors or principal investigators of all relevant studies to ascertain whether any results had been published. No authors identified published studies in response to the e-mail requests.

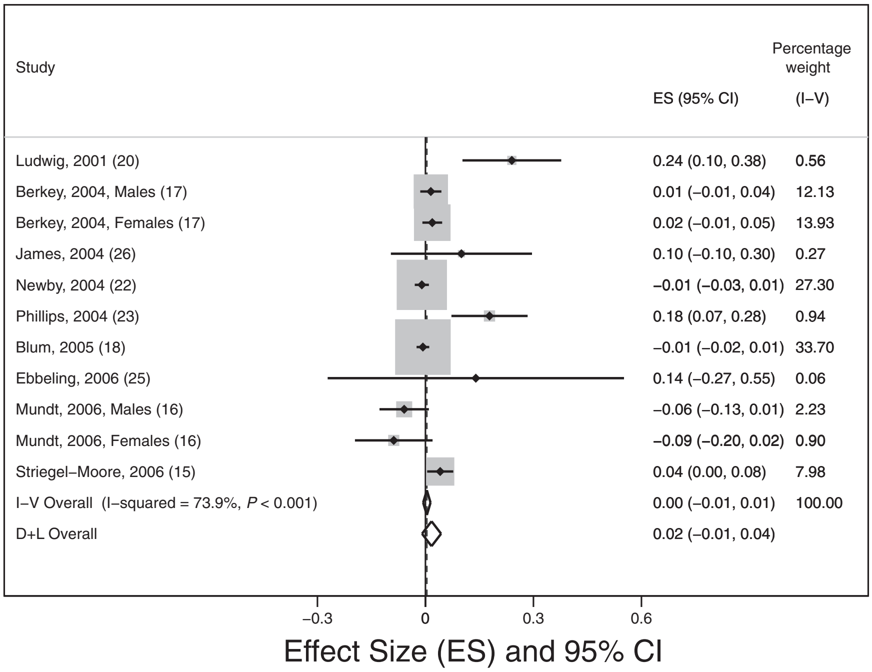

FIGURE 1. Forest plot of studies of sugar-sweetened beverage (SB) consumption and BMI (in kg/m^2) in children and adolescents. I–V, fixed-effects estimate (inverse variance method); D+L, random-effects estimate (Der Simonian and Laird method). The points for each study indicate the reported estimate for the predicted change (Δ) in BMI per serving ΔSB consumption. The size of the gray boxes indicates the weight the study received in the calculation of the overall association and CI. The weight given each study is based on the precision of the estimate. The horizontal lines indicate the 95% CI for each study. The 2 diamonds represent the overall estimate of the predicted ΔBMI per serving ΔSB consumption, based on the pooled results from all studies. The upper open diamond represents the fixed-effects estimation that assumes that the "true" treatment effects in all of the studies are the same. The lower open diamond represents the random-effects estimation that assumes that the true treatment effect may vary across studies. The study by Mrdjenovic and Levitsky (21) was omitted from this forest plot because it had a much larger CI than any other study. The omission of that study does not affect either the fixed-effects or random-effects estimates.

From this search, we identified 2 abstracts that were eligible for inclusion in the meta-analysis. Jimenez et al (29) reported on a prospective cohort of 3070 Mexican adolescents 11–19 y of age. They found a positive association between the percentage of energy from SBs and BMI over time. Respondents who increased the percentage of energy from SBs had greater weight gain ($\beta = 0.4$, 95% CI: 0.19, 0.57) than did those who maintained or reduced the percentage of energy from SBs. The study was supported by Bristol-Myers Squibb Foundation, NY, and CONACyT, Mexico. When the study by Jimenez et al (29) is included in a sensitivity test, the fixed-effects pooled estimate is 0.00 (95% CI: −0.01, 0.01) and the random-effects pooled estimate is 0.03 (95% CI: 0.00, 0.06).

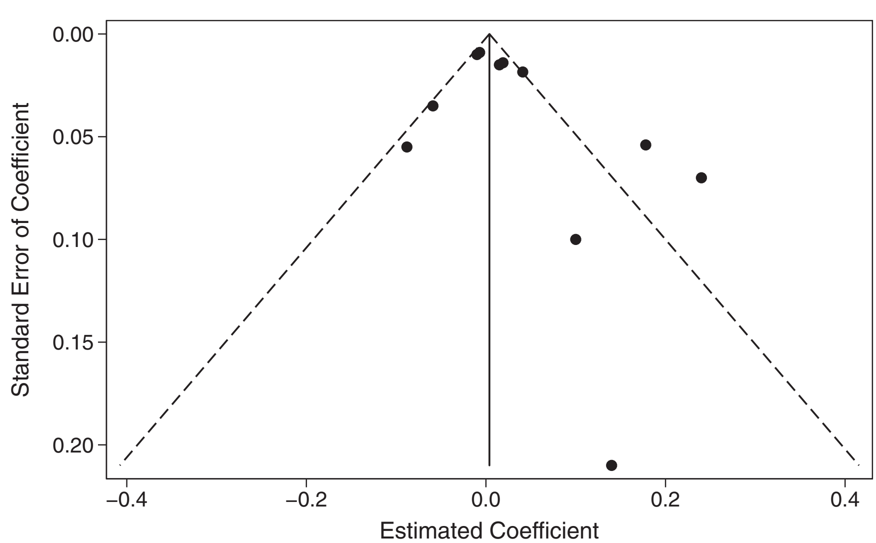

FIGURE 2. Funnel plot of studies of sugar-sweetened beverage (SB) consumption and BMI (in kg/m^2) in children and adolescents. Studies are plotted with the estimated coefficient along the horizontal axis and the SE of the coefficient along the vertical access. In the absence of publication bias, the plot should be symmetric around the average coefficient with greater dispersion among the less-precise studies at the bottom of the plot. The more-precise studies are symmetrically distributed and generally fall within the pseudo-95% CI. The less-precise studies are not symmetrically distributed around the average coefficient. This is consistent with publication bias against studies that did not show statistically significant results.

Gropper et al (30) studied 109 low-income African American children in rural Alabama. When the analysis was restricted to the 80 respondents who reported some SB consumption, they found that the 30% of respondents with the greatest weight gain reported more consumption of SBs (208 ± 22 kcal) than did the 30% of respondents with the lowest weight gain (142 ± 22 kcal). The study was funded by a grant from the US Department of Agriculture. The study by Gropper et al (30) was not included in a sensitivity test because the researchers did not report the association between SB consumption and BMI.

The search did show several important ongoing studies that will eventually contribute new data for any future meta-analysis. We performed 4 sensitivity tests to determine the extent to which assumptions used for the analysis or results from new studies could affect the findings of the meta-analysis.

Sensitivity test 1: effect sizes that are not adjusted for total energy

Berkey et al (17) and Ludwig et al (20) reported the results of models that controlled for total energy as well as models that did not adjust for total energy, and the meta-analysis presented here uses the results from the energy-adjusted models. Using the results from the unadjusted models has a small effect on the results of the meta-analysis. The fixed-effect estimate is 0.008 (95% CI: −0.002, 0.018) and the random-effects estimate is 0.023 (95% CI: −0.004, 0.050).

Sensitivity test 2: 5 more studies comparable to Berkey et al

Berkey et al (17) is a high-quality study showing a positive, nonsignificant relation between ΔSB and ΔBMI. Sensitivity test 2 imagines that 10 more studies (5 for girls and 5 for boys) are reported with the exact same effect sizes and precision as the study by Berkey et al (17). The results from this sensitivity test have nearly the same random-effects estimate (0.015) but a smaller 95% CI (0.004, 0.026) than did the original meta-analysis results. The results of the sensitivity test are statistically significant but close to zero.

Sensitivity test 3: high BMI results of Ebbeling et al

Ebbeling et al (25) reported on the interaction effect between BMI at baseline and the treatment effect. Subjects in the highest tertile of subjects showed a larger treatment effect than did subjects in the first and second tertile. Sensitivity test 3 uses the results from the highest tertile in place of the results for the entire sample and reestimates the model for RCT studies only. Limiting the sensitivity test to RCT studies ensures that the result from Ebbeling et al (25) receives the highest possible weight. The meta-analysis estimates a larger effect size but also larger CIs. The fixed-effects estimates are 0.004 (95% CI: −0.006, 0.014) and the random-effects estimates are 0.019 (95% CI: −0.009, 0.047). Neither estimate is distinguishable from zero. This estimate excludes the subjects in the lower 2 tertiles of baseline BMI, so it may not be generalizable to the entire population.

Sensitivity test 4: blockbuster studies analysis

Fail-safe studies analyze how many studies with null results would be required before the meta-analysis results would not be statistically significant. In this case, the relevant question is whether new studies with large effect sizes and high precision would produce a statistically significant pooled estimate that is large enough to be substantively important.

Sensitivity test 4 adds a "blockbuster" study that reports an effect size ≥2 times as large as any other longitudinal study examined (0.50) and with a precision equal to the most precise estimate of any longitudinal study examined (0.01). With the hypothetical blockbuster study, the fixed-effects estimate is 0.110 (95% CI: 0.101, 0.119) and the random-effects estimate is 0.091 (95% CI: −0.041, 0.224). The fixed-effects estimate is statistically significant, but the random-effects estimate is not statistically significant. A test for heterogeneity shows that the assumptions needed for the fixed-effects estimate are not supported, so the random-effects estimate is the most appropriate one to use.

Limitations

The limitations of each individual study are relevant for the meta-analysis. In particular, measurement error in the instruments used to measure beverage consumption in the longitudinal studies may have affected their results. If the measurement error is random, the standard errors will be larger than they would be in the absence of measurement error. If there is systematic measurement error, the reported coefficients may be biased. However, the longitudinal studies reported used validated dietary instruments that should minimize measurement error as much as possible in self-reported surveys.

The studies used different instruments to measure SB consumption, different measures of weight gain, different statistical models to estimate the effect sizes, and different units of time. Every effort was made to scale the effect sizes to comparable units, but these differences raise the issue of comparability between the studies. The sensitivity tests and tests for the influence of individual studies partially address this limitation.

Most of the studies covered a relatively short time period, typically 1 or 2 y. This limits the ability to assess any long-term effects from SB consumption. Restricting the meta-analysis to children and adolescents limits the ability to extrapolate these results to adults and understand how these dietary patterns carry over into adulthood (31). It is important to note that all of these limitations apply to purely narrative reviews of the literature as well as to meta-analysis.

DISCUSSION

The results of the meta-analysis show that the current science base finds that the relation between SB consumption and BMI among children and adolescents is near zero. The best current scientific evidence shows that the relation between ΔSB consumption and ΔBMI is probably ≈0.02 with an upper confidence limit of 0.04. The overall estimate is not statistically significant. The time period used to assess this relation varied across studies, but the most common time period was 1 or 2 y.

Neither of the RCT studies for children or adolescents found a statistically significant difference in either BMI or weight change (in kg) between the treatment and control groups. Ebbeling et al (25) did find a statistically significant association in the subset of the sample that was in the upper tertile of BMI at baseline, and this possible interaction between BMI and soft drink consumption deserves further study.

A statistical analysis can never definitely state that an association or effect is exactly zero. Given a large enough sample size or enough additional studies, even a small association may be distinguished from zero. However, these results of the quantitative meta-analysis provide a precise estimate of the association of the relation between SB consumption and BMI that is close to zero. Several independent longitudinal studies have consistently found the association to be close to zero with a small CI. Taken as a set, the studies suggest that the association between ΔSB consumption and ΔBMI is ≈0.02, and we can probably rule out any effect size greater than ≈0.04/study period for each serving per day ΔSB unless significant new evidence is presented. For context, the BMI-for-age data from the Centers for Disease Control and Prevention show that during adolescence BMI at the median increases by ≈0.5 unit/y. The average consumption of SB is <2 (12-oz) servings/d even in the age-sex group with the highest consumption of SBs. Completely eliminating two 12-oz servings would reduce BMI by only ≈0.04 with the overall estimate or by ≈0.08 with the upper end of the 95% CI.

Several investigators have recently published critical reviews of the literature on SB consumption and weight gain and have come to different conclusions. A recent meta-analysis that used different methods found a small effect size of SB consumption on weight gain for children. The estimated effect size was $r = 0.03$ with a CI of 0.02 and 0.04 (28). Malik et al concluded that "[t]he weight of epidemiologic and experimental evidence indicates that a greater consumption of SBs 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" (9; p 274). However, 3 other recently published review articles have reviewed much of the same literature and concluded that the evidence for a relation is weak or equivocal (6, 32, 33). The assessment of the literature in those 3 articles found less consistent scientific evidence for the conclusion that SB consumption makes a unique contribution to the risk of weight gain and obesity.

There are 2 primary reasons that these separate reviews reached different conclusions than that of Malik et al (9). First, the other review articles considered the magnitude of the reported associations between SB consumption and BMI in the studies. Even when statistically significant, these associations were generally small. Second, many of the articles cited by Malik et al (9) as supportive of a link between SB consumption and weight gain or obesity contain other findings that contradict any link between SB consumption and obesity other than that which may be associated with its energy content. For example, DiMeglio and Mattes (34), James et al (26), and Ebbeling et al (25) each report no statistically significant difference in BMI or weight gain between the control and treatment groups.

SBs are a source of energy, and excess energy consumption will lead to weight gain. Dietary advice and education for children and adolescents should clearly communicate that SBs should only be consumed in moderation as part of a balanced diet. Children and adolescents who are overweight or at risk of becoming overweight should identify all sources of excess calories and work to modify their diet and increase their physical activity. These results suggest that some form of compensation is going on, and, depending on the form of compensation, it may have beneficial or detrimental health effects. Reducing SB consumption may or may not have other benefits, but these results suggest that the effect on weight will be effectively zero when considering the entire subpopulation of children and adolescents. More research is needed to determine whether certain subpopulations, such as those who are already overweight, may see a weight loss benefit from reducing SB consumption.

Obesity and overweight among children and adolescents are serious public health problems. More studies, particularly RCTs, are needed to investigate proposed processes for reducing obesity. The strongest current evidence is that reducing or eliminating SB consumption would not have a large effect on the BMI distribution of children or adolescents.

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