A systematic review of the association between consumption of sugar-containing beverages and excess weight gain among children under age 12

Julie Frantsve-Hawley, RDH, PhD[1]; James D. Bader, DDS, MPH[2]; Jean A. Welsh, PhD, MPH[3]; J. Timothy Wright, DDS, MS[4]

1 American Association of Public Health Dentistry, Springfield, IL, USA; College of Dentistry, University of Illinois at Chicago, Chicago, IL, USA
2 School of Dentistry, University of North Carolina, Chapel Hill, NC, USA
3 Department of Pediatrics, Emory University School of Medicine, Wellness Department, Children's Healthcare of Atlanta, Nutrition and Health Sciences Doctoral Program, Laney Graduate School, Emory University, Atlanta, GA, USA
4 Department of Pediatric Dentistry, UNC School of Dentistry, Chapel Hill, NC, USA

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Correspondence
Julie Frantsve-Hawley, American Association of Public Health Dentistry, College of Dentistry, University of Illinois at Chicago, Chicago, IL.
Tel.: 847-999-8852; Fax: (217) 529-9120; e-mail: jhawley@aaph.org.
James D. Bader is with the School of Dentistry, University of North Carolina.
Jean A. Welsh is with the Department of Pediatrics, Emory University School of Medicine, Wellness Department, Children's Healthcare of Atlanta, Nutrition and Health Sciences Doctoral Program, Laney Graduate School, Emory University. Timothy Wright is with the Department of Pediatric Dentistry, UNC School of Dentistry.

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Abstract

Objective: A systematic review was conducted to address this clinical question: Does consumption of (non-dairy) sugar-containing beverages (SCBs) among children under age 12 result in excess weight gain?
Methods: The authors searched four databases for controlled trials (randomized and non-randomized) and cohort studies published in English through March 29, 2016: PubMed, EMBASE, Cochrane Database of Systematic Reviews, CINAHL. Initial and full-text screening, data abstraction, and risk of bias assessment were performed independently and in duplicate.
Results: Thirty-eight studies met inclusion criteria for this systematic review. One was a randomized controlled trial, and 37 were cohort studies. Though the results of these studies were mixed, the majority demonstrated a statistically significant positive association between SCB consumption in children under age 12 and total adiposity and central adiposity. In contrast, most studies that assessed 100 percent fruit juice consumption only with either total adiposity or central adiposity did not support an association. Among only children under age 5 at baseline, no studies examined central adiposity, but nearly all studies examining SCBs and total adiposity, and a majority examining only fruit juice consumption, demonstrated a statistically significant positive association.
Conclusion: Our results support a statistically significant positive association between SCBs and total and central adiposity among children under age 12. This association is most consistent for total adiposity among children <5. Our results for 100 percent fruit juice only suggest differences by age, as most studies among those < 12 were negative but most among those <5 were positive.

Introduction

The prevalence of childhood obesity, which has more than doubled in US children and quadrupled in adolescents since the 1970s (1), has risen to epidemic proportions. Currently, 17 percent of US children are obese and at increased risk of chronic obesity and related conditions (1). Efforts to reverse this trend have focused on developing strategies that can modify the lifestyle factors that have contributed to this rise. The increased consumption of (non-dairy) sugar-sweetened beverages (SSBs), which has occurred in parallel to the rise in obesity, has fueled concerns that it may be playing a causal role (2).

SSBs such as sodas, fruit-flavored drinks, and sports drinks are the leading source of added sugars, and a leading source of calories, in the US diet (3,4). Added sugars are those added during the processing or preparation of foods and beverages. Guidelines from the US Department of Agriculture, the

Centers for Disease Control and Prevention, the World Health Organization, and the American Heart Association all advise that added sugar consumption be limited (5,6). Multiple systematic reviews have concluded that there is a positive association between SSB consumption and increased obesity risk, but the studies included in these reviews were done primarily among adolescents and adults (7,8). Adolescent dietary behaviors may dramatically change as a result of increased peer influences and decrease of parental influences, thus there remains uncertainty on the association between SSB and obesity in children under 12. Furthermore, Robert Wood Johnson Foundation obesity-related goals include ensuring that all children enter kindergarten at a healthy weight and eliminate the consumption of SSBs among 0-5 year olds.

Research examining the association between SSB consumption and obesity risk have primarily used total adiposity, which is relatively easy to assess using body mass index (BMI), as their outcome of interest. While less commonly studied, body fat distribution, specifically fat distributed centrally, is also of interest given the role that body fat distribution plays in increasing metabolic risk (9-12). The results of some studies suggest that SSB consumption may increase central adiposity (9), although no systematic reviews have been done to assess the totality of this evidence.

While SSB consumption begins for many children before they reach their first birthday, 100 percent fruit juice is more commonly consumed among young children (13). Given the similarity in nutrient content between 100 percent fruit juice and SSBs, both of which are composed primarily of sugar and water, concerns have also been raised about children's risk of obesity associated with 100 percent fruit juice consumption (14). Few studies, and no systematic reviews, have examined the association between the fruit juice consumption and obesity among young children.

Several possible mechanisms have been proposed to explain a possible association between obesity and consumption of SSBs and 100 percent fruit juice, collectively referred to as sugar-containing beverages (SCBs). Some proposed mechanisms include those that involve mediation by total energy intake. The presence of sugar may increase the palatability of foods and contribute to overriding normal satiety signals, leading to overconsumption of calories (15). Similarly, the results of several studies suggest that there is incomplete compensation for calories consumed in beverages versus foods, leading to excess intake (16-18). Other hypothesized mechanisms include those that do not involve mediation by total energy and are specific to the metabolic features of the sugars (glucose and fructose) consumed in most SCBs. Glucose intake elicits an insulin response that may, with chronic high intake, lead to insulin resistance and a tendency toward the storage rather than burning of excess calories (18,19). Fructose, conversely, does not result in an insulin response. The metabolism of fructose, which is largely unregulated, occurs almost exclusively in the liver where, with high consumption, fat may accumulate, leading to increased insulin resistance and obesity (20).

The purpose of this review was to evaluate the available evidence examining the longitudinal association between adiposity and the consumption of SCBs (SSBs and 100 percent fruit juice), and between adiposity and the consumption of only 100 percent fruit juices among children under age 12.

Methods

A systematic review was conducted according to the PRISMA Guidelines (21) to address this clinical question: *Does consumption of sugar-containing beverages among children under age 12 result in excess weight gain?* The study protocol was determined a priori. The following databases were searched for articles through March 29, 2016: PubMed, EMBASE, Cochrane Database of Systematic Reviews, CINAHL and the NIH Reporter. Search terms included "sugar-sweetened beverages," "naturally sweet beverages," "caloric sweetener," "juice," "fruit drinks," "soda," "pop," "soda pop," "ades," "punches," "soft drink," "sports drink," "energy drinks," "tea," "coffee," "obesity," "weight gain," "overweight," "BMI," "adiposity," "waist circumference," and "central adiposity." See Appendix 1 for the full search strategy.

This systematic review examined two different exposures. The first exposure was SCBs, which include all sugar-sweetened (non-dairy) beverages and 100 percent fruit juice. The specific beverages included varied widely between studies. A detailed listing of the beverages included can be found in Table 1. The second exposure was 100 percent fruit juice only. As per the definition used by the US Food and Drug Administration, we assumed that reports of "fruit juice" consumption meant 100 percent fruit juice unless otherwise specified (22).

Inclusion criteria were:

- Exposure: caloric (non-dairy) SCB
- Outcome: change in total or central adiposity
- Subjects under age 12 at baseline
- English language
- Cohort or controlled clinical trials (randomized and non-randomized)

Exclusion criteria were:

- Studies examining beverages sweetened with non-caloric sweeteners
- Studies examining dairy beverages (flavored or unflavored milk and yogurt drinks)
- Cross sectional and case-control designs

Table 1 Characteristics of Included Studies

Author/year	Study design	Country	Population	Age at baseline	Follow-up term	n	Outcome variable	Sugar-sweetened beverage (SSB) definition	Fruit juice only	Time of beverage consumption assessment	Source of funding	Risk of bias
Bigornia 2015	Cohort	England	Avon Longitudinal Study of Parents and Children: all pregnant women in Avon with an expected delivery date between 4/1/1991 and 12/31/1992.	10 years	3 years	2,455	Body mass index (BMI), waist circumference (WC), total body fat mass (TBFM)	Sodas/soft drinks (S/SD), fruit-flavored drinks, fruit squashes, cordials		At ages 10 and 13 (study completion)	UK Medical Research Council, Welcome Trust, American Diabetes Association	Mod.
Cantoral 2016	Cohort	Mexico	Two birth cohorts followed from birth to 5 years, and at a later date	8-14 years; 47% were 8-9 years	8-14 years	227	BMI, WC	S/SD, fruit-flavored drinks, flavored water with sugar		Every 6 months from ages 1-5; cumulative total used as exposure	National Institute of Environmental Health Science federal grant	Mod.
De Boer 2013	Cohort	United States	Early Childhood Longitudinal Survey birth cohort	2 years at baseline	3 years	9,600; not in all analyses	BMI standard deviation (BMIz)	S/SD, fruit-flavored drinks, sports drinks		2 and 4 years	Not reported	Low
De Coen 2014	Cohort	Belgium	Pre-primary and first-year primary school children in three towns in Flanders; 19% overweight at baseline	3-6 years	18 months, 30 months	568	BMIz % Body Fat	S/SD		Baseline	Ministry of Flemish Community	High
De Ruyter 2012	RCT	Amsterdam	Schoolchildren	4 years 10 months to 11 years 11 months	18 months	641	BMIz, WC, % body fat, waist-to-height ratio	Sugar containing non-carbonated beverage		Children drank one can of sugar-containing beverage or control beverage/day	Netherlands Organization for Health Research and Development, Nether-lands Heart Foundationand Royal Netherlands Academy of Arts and Sciences	High
Dong 2015	Cohort	England	Avon Longitudinal Study of Parents and Children: all pregnant women in Avon with an expected delivery date between 4/1/1991 and 12/31/1992	Two spans: 7-10 years; 10-13 years	Two 3-year periods	4,646	BMIz	100% fruit juice, SSB	Yes	Baseline and study completion	None reported	Mod.
Dubois 2007	Cohort	Canada	Longitudinal Study of Child Development in Quebec	2.2 years at baseline; 4.5 years at end	2 years	1,499	BMI	S/SD, fruit-flavored drink		Age 2.5 at baseline and 4.5 at study completion	Canadian government	Low
Faith 2006	Cohort	United States	Children in New York WIC program	1-4 years	up to 48 months	825	BMI, BMIz	Not applicable	Yes	Baseline	Economic Research Service, Food Assistance and Nutrition Research Program, US Department of Agriculture (USDA) grant	Mod.
Feng 2016	CCT, but data analyzed as cohort	United States	Hispanic children from families with low incomes	5-9 years	22 months	555	BMI, WC, % body fat	S/SD, fruit-flavored drinks, sports drinks, sweet tea, lemonade		5 times during study period	USDA	Mod.

Table 1. Continued

Author/year	Study design	Country	Population	Age at baseline	Follow-up term	*n*	Outcome variable	Sugar-sweetened beverage (SSB) definition	Fruit juice only	Time of beverage consumption assessment	Source of funding	Risk of bias
Fiorito 2009	Cohort	United States	Non-Hispanic white girls	5 years at baseline	10 years	166	BMI, WC, % body fat	S/SD, fruit-flavored drinks, 100% fruit juice, sports drinks, sugar-sweetened coffee or tea		Every 2 years from age 5 (baseline) to age 15 at study completion	NIH Grant, National Dairy Council	Mod.
Guerrero 2016	Cohort	United States	Birth sample cohort, data from home visits at 9, 24, 48, 60, and 72 months	48 months at baseline	2 years	15,418	BMI	S/SD, fruit-flavored drinks, 100% fruit juice	Yes	Baseline and every 12 months	US Department of Health and Human Services, University of California, the McCormick Foundation	Low
Hasnain 2014	Cohort	United States	Descendants of the Framingham cohort study – Non-Hispanic white children with two-parent families	3-5 years	12 years	98	BMI, WC, % body fat	S/SD, fruit-flavored drinks, 100% fruit juice, sweetened tea/ coffee		Baseline, annually for 12 years and at study completion	National Heart and Lung Institute, National Dairy Council	Low
Hur 2015	Cohort	Korea	Korean children	9-10 years	4 years	605	BMIz, % body fat	S/SD, fruit-flavored drinks, 100% fruit juice, sports drinks, energy drinks, vegetable drinks, coffee, sweet tea, soy milk, energy drinks, and other beverages		Baseline	Korean Ministry of Food and Drug Safety	Mod.
Jensen 2013	CCT, but data analyzed as cohort	Denmark	Danish children	6 years	7 years	513	BMI, % body fat	S/SD, fruit-flavored drinks, 100% fruit juice, chocolate milk, drinkable yogurt, squash		Baseline and at 3 years	Trygfonden, Center for intervention Research in Health Promotion and Disease Prevention, Danish Heart Foundation, Familien Hede Nielsen Foundation, University of Southern Denmark	Mod.
Kuhl, 2014	Controlled clinical trial (CCT), but data analyzed as cohort	United States	Families with children age 2-5 years whose BMI was ≤ 95th percentile but who were <100% over their ideal body weight; at least one parent also had to be overweight	2-5 years	6 months	36	BMIz	Not defined		Baseline and study completion	National Institutes of Health (NIH)	High
Laurson 2008	Cohort	United States	Subjects ages 10 years rural US children; participants were from three areas in Idaho (40.3%), Montana (34.3%), and Wyoming (25.4%)	10 years	18 months	221	BMI, BMI-for-age as per International Obesity Task Force	Soda pop, sweetened drinks such as Kool-aid or Gatorade		Baseline and study completion	Initiative for Future Agriculture and Food Systems competitive grant program/USDA	Low

Table 1. Continued

Author/year	Study design	Country	Population	Age at baseline	Follow-up term	*n*	Outcome variable	Sugar-sweetened beverage (SSB) definition	Fruit juice only	Time of beverage consumption assessment	Source of funding	Risk of bias
Laverty 2015	Cohort	UK	18,818 children ages 7-11 years in the UK Millennium Cohort Study, collected in 2008 and 2012	7 years	4 years	10,283	BMI, BMIz, % body fat	Sweetened drinks (e.g., cola, squash, or Sunny Delight)		Study completion	Not reported	Low
Lee 2015	Cohort	United States	African-American and white girls	9-10 years	7+ years	1,975	BMIz; WC	Naturally occurring liquid sources of glucose, fructose, or sucrose	Yes	Baseline, completion, and other	Children's Healthcare of Atlanta	Low
Lim 2009	Cohort	United States	365 African-American preschool children ages 3-5 years from families with low incomes	3-5 years	2 years	365	BMIz, change in BMIz, % body fat	Soda (excluding diet soda) and fruit drinks (including Kool-Aid, Gatorade, Sunny Delight, Hi-C, Hawaiian Punch, Ocean Spray) excluding 100% fruit juice		Baseline, study completion and other	National Institute for Dental and Craniofacial Research, University of Michigan, Delta Dental Fund of Michigan, Clinical Sciences Scholars Program at the University of Michigan	Low
Millar 2014	Cohort	Australia	Longitudinal Study of Australian Children (LSAC)	4-5 years at wave 1	6 years	4,169	BMIz	Fruit juice; soft drink or cordial (not diet)		Baseline, study completion and other	Department of Families, Housing, Community Services and Indigenous Affairs, the Australian Institute of Family Studies and the Australian Bureau of Statistics	Low
Muckelbauer 2016	Cohort	Germany	German elementary school students (two districts)	Elementary school; mean age 8.3 years	One school year	2,950	BMI, prevalence of over-weight and obesity	Soft drinks (lemonades and ice tea) and juices (fruit drinks of any percentage fruit juice)	Yes	Baseline and study completion	The secondary analysis received no specific grant from any funding agency, commercial or not-for-profit sectors	Mod.
Newby 2004	Cohort	United States	Children participating in the North Dakota WIC program	2-5 years	6 months	1,345	BMI	100% juice, sodas (excluding diet), fruit drinks (excluding lemonade and fruit punch)	Yes	Baseline	USDA, NIH, Harvard Education Program in Cancer Prevention Control, and Boston Obesity Nutrition Research Center	Mod.
Pan 2014	Cohort	United States	Children who participated in the Infant Feeding Practices Study II (a nationwide longitudinal study on infant health,	10-12 months	6 years	1,189	Obesity prevalence	S/SD, fruit-flavored drinks, 100% fruit juice, sweet tea, Kool-Aid		Baseline, study completion and other	USDA, Centers for Disease Control and Prevention (CDC), Office of Women's Health, National	Mod.

Table 1. Continued

Author/year	Study design	Country	Population	Age at baseline	Follow-up term	*n*	Outcome variable	Sugar-sweetened beverage (SSB) definition	Fruit juice only	Time of beverage consumption assessment	Source of funding	Risk of bias
			food intake, and infant feeding practices) in 2005-2007 and were followed up at 6 years in 2012								Institutes of Health, and Maternal and Child Health Bureau	
Shefferly 2016	Cohort	United States	8,950 children examined at ages 2, 4, and 5 years as part of the Early Childhood Longitudinal Study – Birth Cohort, a representative sample of the United States	2, 4, and 5 years	2 and 3 years	8,950	BMIz, Obesity prevalence	Not applicable	Yes	Baseline and study completion	NIH, Doris Duke Charitable Foundation Career Development Award	Low
Sichieri 2013	Cohort	Brazil	Secondary analysis of a randomized school trial of fourth graders from 22 public schools in the city of Nitero´i, located in the metropolitan area of Rio de Janeiro, Brazil	10-11 years	One school year	1,134	BMI, BMIz	Sodas (colas and other sodas), guaraná natural (a Brazilian non-carbonated SSB), natural and industrialized fruit juices	Yes	Baseline	Brazilian National Research Institute and the Foundation of Research from Rio de Janeiro State	High
Skinner 2001	Cohort	United States	White children residing in the vicinity of a Southern US city; 37 boys, 35 girls; middle or upper socioeconomic-status (SES) families, and all the parents except one mother had some education beyond high school	24, 28, or 32 months	4 years	72	BMI	Not applicable	Yes	Baseline, study completion and other	Gerber Products Company, and Tennessee Agricultural Experiment Station	Mod.
Skinner 1999	Cohort	United States	105 healthy, white children, 62 of whom were part of a longitudinal study about food habits of children age 2-60 months; from families with middle to high incomes (an additional 43 children from families with low incomes were later enrolled)	24, 28, or 32 months at interview 1; 28, 32, or 36 months at inter-view 2	4 months	105	BMI	Not applicable	Yes	Baseline	Gerber Products Company and the Tennessee Agricultural Experiment Station	High
Sonneville 2015	Cohort	United States	Participants were recruited at their initial prenatal visit from 8 urban and	1 year at baseline; mean 7.7 years at follow-up	6 years	1,163	BMIz	Not applicable	Yes	Baseline, study completion and other	CDC, NIH, Harvard Medical School, and	Low

Table 1. Continued

Author/year	Study design	Country	Population	Age at baseline	Follow-up term	*n*	Outcome variable	Sugar-sweetened beverage (SSB) definition	Fruit juice only	Time of beverage consumption assessment	Source of funding	Risk of bias
			suburban obstetric offices of Harvard Vanguard Medical Associates in Massachusetts between 1999 and 2002								Harvard Pilgrim Health Care Foundation	
Striegel-Moore 2006	Cohort	United States	Black and white girls ages ~9-10 years who participated in the National Heart, Lung and Blood Institute (NHLBI) Growth and Health Study	Girls 9-10 years	9 years	2,371	BMI	Regular soda (all non-diet carbonated beverages, except water); fruit juices (fruit and vegetable juices); and fruit drinks (fruit-flavored drinks, punches, ades)	Yes	Baseline and study completion	NHLBI, contract HC55023-26 and cooperative agreement U01-HL-48941-44	Low
Tam 2006	Cohort	Australia	Birth cohort of infants born at term at Nepean Hospital in western Sydney August 1989-April 1990	7.7 ± 0.6 years	5 years	281	BMI	Soft drink/cordial (sugar-sweetened fruit juice/drink)		Baseline	Not reported	High
Weijs 2011	Cohort	Netherlands	Infants (looking at overweight risk 8 years later)	4-13 months	8 years	120	BMI standard deviation score	Any drinks containing mono- and/or disaccharides, excluding milks, thus both naturally sweetened, sweetened by industry or sweetened at home		Baseline and study completion	Amsterdam Ministry of Health, Welfare and Sports	High
Welsh 2005	Cohort	United States	Children participating in WIC ages 2-5 years	2-3 years	1 year	10,904	BMI, incidence and persistence of overweight	Sweet drinks included vitamin C-containing juices, other juices, fruit drinks, and sodas	Yes	Baseline	Not Reported	Mod.
Wheaton 2015	Cohort	Australia	LSAC nationally representative sample), identified through the Medicare Australia enrollment database, which contains the majority of Australian children's details	4-5 years	6 years	4,169	BMIz	Fruit juice; soft drink or cordial (not diet)		Unclear	Australian government, NIH	Low

Table 1. Continued

Author/year	Study design	Country	Population	Age at baseline	Follow-up term	*n*	Outcome variable	Sugar-sweetened beverage (SSB) definition	Fruit juice only	Time of beverage consumption assessment	Source of funding	Risk of bias
Wijga 2010	Cohort	Dutch	Dutch asthma study	5 and 7 years	3 years	1,871	BMI	Soft drinks ("4 types of soft drinks")		Baseline; mean of two measures at 5 and 7 years	Not reported	Low
Zheng (*J Hum Nutr Diet*) 2015	Cohort	Australia	Childhood Asthma Prevention Study	9 years	3.5 years	158	BMIz, % body fat	Regular soft drinks, fruit drinks, cordials and sugar-sweetened sport drinks; 100% fruit juice (apple, black currant, grape, orange, and fruit blend)	Yes	Midpoint	Not reported	High
Zheng (*Br J Nutr*) 2015	Cohort	Denmark	2-6-year-old Danish children who were normal weight, but had a high predisposition for future overweight	2-6 years	1.5 years	288	BMIz, % body fat	Sugary drinks (sugar-sweetened carbonated and fruit-flavored drinks and fruit juice)		Baseline and study completion	No specific grant from any funding agency, commercial, or not-for-profit sectors	Mod.
Zheng (*Eur J Nutr*) 2015	Cohort	Denmark	Danish part of the European Youth Heart Study	9 years	6 years	358	BMIz, WC, % body fat	Regular soft drinks, lemonade, or fruit-flavored drinks; 100% pure fruit juice	Yes	Baseline	Not reported	Mod.
Zheng 2014	Cohort	Denmark	European Youth Heart Study	9 years	12 year follow-up	187	BMI, WC, % body fat	Soft drinks, fruit drinks, and cordials sweetened with caloric sweeteners; excluded 100% fruit juice, flavored milk, coffee, and tea		Baseline and first follow-up	Not reported	Low

- Lack of both baseline and end-of-study data on total or central adiposity
- Studies focused on children with chronic health conditions, (e.g., diabetes, asthma)

Initial screening by title and abstract and full-text screening were performed in duplicate by teams, with each team screening half of the studies. Discrepancies were reviewed by a member of the opposite team, with additional discussion if necessary. Hand searching included screening other systematic reviews addressing the same topic as well as reference lists of included studies (7,8,23-36).

Data abstraction and critical appraisal of included studies were likewise performed in duplicate by teams, with discrepancies addressed in the same manner. In abstracting the data, we identified the analyses that evaluated the association between SCB exposure at one of more time points and change in total and/or central adiposity. For studies with multiple time points, data from the longest time point were abstracted. For studies that examined more than one exposure dosage or frequency, the results for the greatest amount/frequency were included. For studies that reported on multiple relevant outcomes, an a priori decision was made to include data from one of the outcomes only based on the following hierarchy for total adiposity measures: BMI z-scores (BMIz), BMI, percentage of body fat, weight change, incidence of obesity, incidence of overweight, prevalence of obesity, prevalence of overweight, and on the following hierarchy for central adiposity measures: waist circumference, weight to hip ratio. When all results for the same exposure and outcome analysis were presented stratified by subgroup (e.g., weight status at baseline), only results for the subgroup with the largest sample size were included in the review. We recorded all of the covariates that were included in that analysis. Data from separate publications that used the same cohort but evaluated different exposures or different outcomes were included as separate studies.

The Cochrane protocol randomized controlled trial (RCT) risk of bias assessment (37) and a modified version of the Critical Appraisal Skills Programme (CASP) were used for Cohort study risk of bias assessment (38). The selected CASP critical appraisal questions, and rating criteria, were used (Appendix 2). Studies were judged for overall risk of bias based on the following criteria:

- Low: 0-2 Unclear/Partial and 0 No
- Moderate: 3-5 Unclear/Partial and/or 0-1 No
- High: 6+ Unclear/Partial or 2+ No

Meta-analyses were planned to be performed whenever possible, both overall and by subgroup. Subgroups identified for separate analyses were age (0-less than 5 and 5-12 years), adiposity (total and central), SCBs (fruit juice only), total energy (adjustment and no-adjustment), and study design (cohort and controlled trials).

Results

The outcomes of the literature search are described in Figure 1. After duplicates were removed, 2,887 citations were screened in two phases. In the first phase, screening of titles and abstracts yielded 124 citations for full-text review. In the second phase, full-text versions of these studies were screened. Eighty-six citations were excluded (Appendix 3). Thirty-eight citations met the inclusion criteria for this systematic review, of which 34 were cohort studies (12,39-70), One was an RCT (71), and 3 were controlled clinical trials where data from the various groups were the study authors combined groups for analysis as a cohort study (72-74).

Some of the studies included in this systematic reviewed performed analyses of different exposures and/or outcomes of interest using the same data set, such as Bigornia et al. (12), and Dong et al. (46), Zheng et al. (65), and Zheng et al. (64), Shefferly et al. (55), and DeBoer et al. (68), Millar et al. (53), and Wheaton et al. (66). Study characteristics for each included study were abstracted (Table 1). Fifteen studies were judged to be at low risk of bias, 15 at moderate risk of bias, and 8 at high risk of bias (Appendices 4A and 4B).

Due to methodological heterogeneity in terms of study designs, exposures and exposure measures, populations, analysis designs, outcome measures, and covariates, meta-analyses could not be performed. Thus, this review relied on "vote counting," a means of using the presence or absence of statistically significant results, to summarize the available evidence (75). In cases where the analysis was repeated with or without controlling for total energy, the results for that study were considered positive if either of the analysis demonstrated a statistically significant finding using a P-value $P < 0.05$ or confidence interval for a relative risk or odds ratio that did not include 1 or a β coefficient that did not include 0. In addition, in the two cases where 10 or more studies were available that examined the same exposure (SCBs or fruit juice only) and outcome (total or central adiposity), we conducted a two-tailed sign test to assess the weight of the evidence of an any effect in either direction (75,76). In these cases, if results varied across multiple analyses, the findings relevant to the most commonly consumed beverage or the largest subsample were considered.

Association between SCB consumption and total adiposity in children under age 12

All studies

Thirty-one studies addressed the association between SCB consumption and total adiposity in children under age 12 at baseline (Table 2A). Among these, 19 studies demonstrated a statistically significant positive association (either with or without control for total energy intake, or both) between SCB consumption in children under age 12 at baseline and

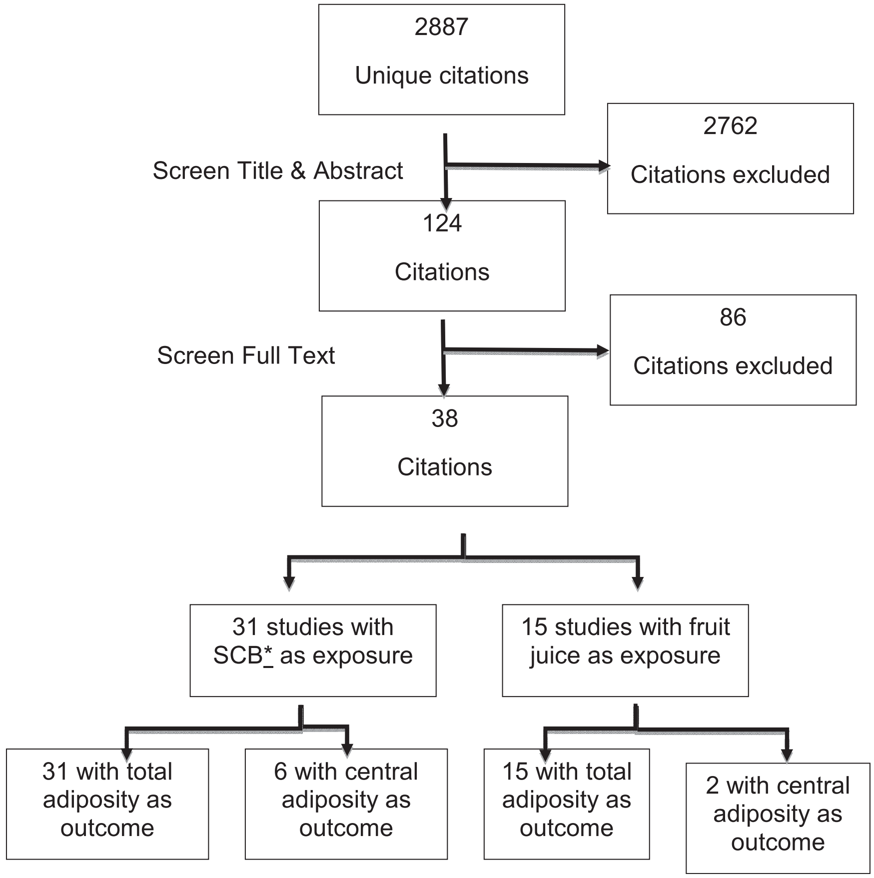

Figure 1 Literature search results. PubMed, EMBASE, Cochrane Database of Systematic Reviews, CINAHL, and NIH Reporter were searched through March 29, 2016. 2887 unique citations were screened in duplicate in two phases. The first phase screen of title and abstract yielded 125 citations, and the second phase screen of full text yielded 38 citations that met the inclusion criteria for this systematic review. *SCB, sugar containing beverages (sugar sweetened beverages and 100 percent fruit juice).

total adiposity. Twenty-nine of these 31 studies did not control for total energy in their analysis, 17 (59 percent) of which demonstrated a statistically significant positive association. Among the 13 studies that controlled for total energy intake, the association was significant in 6 studies (46 percent). The results of the two-tailed sign test for these studies, which takes into account the direction of the association regardless of whether the results were statistically significant, were 23 studies with a positive association, 7 with a negative association, and one tie, $P = 0.0052$ (two-tailed).

Studies with change-over-change analyses

Seven studies used a study design that allowed for the evaluation of the change in SCB consumption and change in total adiposity over the same time period. Of these, 4 out of 7 studies (57 percent) demonstrated a statistically significant positive association between change in SCB consumption and change in adiposity (46,47,54,61). Out of the 24 studies that did not conduct a change-over-change analysis, 15 demonstrated (63 percent) a statistically significant positive association between change in SCB consumption and change in adiposity (12,48,50,52,53,60,62,63,66-68,71,72,77,78).

Table 2B summarizes the frequency of the included studies with a positive association between SCB consumption and total adiposity, considering risk of bias assessment and study design features that could potentially be biasing or confounding the results.

Association between SCB consumption and central adiposity in children under age 12

Six studies assessed the association between SCB consumption and central adiposity in children under age 12 (Table 3A). Five out of 6 studies that were uncontrolled for total energy had a statistically significant result demonstrating a positive association. Two of these studies also controlled for total energy intake. In one of these (47), the results remained significant when controlling for total energy, and in the other the association was no longer significant when total energy was included in the model ($P = 0.07$) (65).

Table 2A Data Abstraction for Association Between Sugar-Containing Beverage Consumption and Total Adiposity in Children Under Age 12

Author/year	Results not controlled for total energy	Results controlled for total energy	Covariates
Bigornia 2015	*Effect of increased sugar-containing beverage (SCB) consumption (serving/day) on body mass index (BMI) $\beta = 0.074$ (SE = 0.04) $P < 0.001$		Sex, age, height, adiposity, physical activity at age 13 years; pubertal stage at age 13 years; maternal overweight/obesity status; maternal education; dieting at age 13 years; change in fruit juice, fruit and vegetable, and total fat intakes from ages 10 to 13 years.
Cantoral 2016	*Unadjusted odds ratio (OR) of obesity for those in the third compared to the first tertile of SCB consumption 2.69 (95% CI 1.25, 5.79)	*Adjusted OR of obesity for those in the third compared to the first tertile of SCB consumption 2.99 [95% confidence interval (CI) 1.27, 7.00]	Age at introduction of SCB, sex, age, TV watching, physical activity, non-SSB total energy intake, breastfeeding up to age 12 months, maternal obesity at 12 months postpartum.
De Boer 2013	*Greater increase in BMI standard deviation (BMIz) among those consuming of SCB/day compared to those consuming less $P < 0.05$		Race/ethnicity, socioeconomic status (SES)
De Coen 2014	Association between soft-drink consumption (ml/day) and odds of overweight OR 1.36 (95% CI 0.77, 2.40)		Overweight at baseline, living situation, N children in family, maternal and paternal (M&P) education level, language spoken, M&P professional status, M&P overweight, water consumption, milk products consumption, fruit consumption, vegetable consumption, sweet and savory snack consumption, physical activity at home, structured physical activity, screen time – week, screen time – weekend.
De Ruyter 2012	*Change in BMIz in sugar-free beverage group versus sugar beverage group Mean difference: −0.13 (95% CI −0.20, −0.06) $P = 0.001$		No confounders – true randomized controlled trial, however, not controlled for beverage consumption outside of school.
Dong 2015	*Estimated 3-year excess weight gain per 100 g increase in daily intake of SCB (change-change model) = 35 g $P < 0.05$		Fat spread, nuts, coated poultry, potato chips, coated fish, processed meats, uncoated fish, French fries and roasted potatoes, meats, uncoated poultry, canned fruit, eggs, desserts and sweets, full-fat milk, low-fat milk, sugar-sweetened beverages (SSBs), fruit, potatoes not cooked in oil, juices, diet soda, vegetables, yogurt, cheese, refined grains, non-high-fiber breakfast cereal, whole grains, high fiber cereal.
Dubois 2007	*Association of being overweight and regular SCB consumption between meals OR 2.36 (95% CI 1.105, 5.054)	*Association of being overweight and regular SCB consumption between meals OR 2.356 (95% CF 1.030, 5.390)	Sex, maternal smoking during pregnancy, physical activity, birthweight, income level, n of overweight parents, consumption of fruits and vegetables, grain products, milk products, meat and alternatives.
Feng 2016	Change in BMI percentile with daily SCB intake ß = −0.00 (SE = 0.03) *P*-value NS		Group membership, parents' education and acculturation, family income, family meals, child gender and age at baseline, child fast food intake and daily TV time, home availability of SSBs.
Fiorito 2009	*BMI percentile positively associated with higher SCB consumption $P < 0.05$	*Increased % body fat (0.18) with SCB consumption $P < 0.05$	Gender, sex, physical activity were controlled in the study, but not in the relevant analysis.

Table 2A. Continued

Author/year	Results not controlled for total energy	Results controlled for total energy	Covariates
Guerrero 2016	*BMI change with any versus no soda ß = 0.138 (SE = 0.037) $P < 0.01$		Age, sex, race, birthweight, N parents in household, poverty status, maternal education, acculturation, breastfeeding history, fast food consumption, fruits consumption, vegetables consumption.
Hasnain 2014	Association of SCB daily consumption tertiles with mean BMI (Data presented only as a figure) $P = 0.42$		Age, baseline body fat, mean TV and video time, other beverages, maternal education, maternal BMI.
Hur 2015	Unadjusted association of SCB (g/day) at age 9-10 with BMI at age 13-14 $\beta = -0.02$ (SE = 0.02).	Adjusted association of SCB (g/day) with BMI $\beta = -0.02$ (SE = 0.03)	Multiple regression (Table 4) was controlled for sex, age, household income.
Jensen 2013	Association of ΔSCB at age 6 years with ΔBMI from age 6 years to age 13 years $\beta = -0.0592$ (95% CI −0.1453 to 0.0270) $P = 0.17$		Model 2 (Table 2) Adjusted for baseline BMI, body fat, cluster effect by school, gender, and intervention/control group.
Kuhl 2014		Association of ΔSCB consumption with ΔBMIz score $\beta = 0.191$ (95% CI −0.011 to 0.040)	Fruits and vegetables, sweet and salty drinks, physical activity, screen time.
Laurson 2008	ΔBMI with each additional SCB/week: Boys: β −0.037 (SE = 0.019) $P = 0.707$ Girls: β 0.086 (SE = 0.027) $P = 0.405$		Age, gender, baseline BMI, change in height, ethnicity, state of residence, physical activity, screen time, milk consumption, fruits and vegetables, eating with family.
Laverty 2015	*ΔBMIz with consumption of SCBs daily versus less than once/week $\beta = 0.07$ (CI 0.02; 0.11)		Models adjusted for: ethnic group, equivalized income, mother's highest educational qualification, country, portions of fruit consumed/day, breakfast consumption, days per week of sport/exercise, hours spent watching TV per weekday, mode of transport to school, being on a controlled diet at age 7 and snacking at age 7, adiposity at age 7.
Lim 2009	Unadjusted odds of incident overweight with each additional oz/day of SCBs OR = 1.02 (CI: 1.00-1.04)	*Adjusted odds of incident overweight with each additional oz/day of SCBs OR = 1.04 (1.01-1.07)	Baseline beverage intakes, BMI, age, gender, caregiver's education and income, child's baseline dietary energy, caregiver's BMI.
Millar 2014	*ΔBMI with each additional intake of SCB/day: $\beta = 0.015$ (CI: 0.004, 0.025) $P < 0.01$		Fat intake, household income, mother's BMI, sex, wave, location.
Muckelbauer 2016	*ΔBMI with each additional glass of SCB/day $\beta = 0.02$ (95% CI: 0.00, 0.03) $P = 0.01$		Baseline BMI, baseline and change in consumption of all beverage categories, age, sex, migrational background, study arm, and follow-up duration.
Newby 2004	ΔBMI with each additional oz/day of: fruit drinks $\beta = -0.01$ (SE = 0.01), $P = 0.31$ soda: $\beta = -0.02$ (SE = 0.02), $P = 0.34$	ΔBMI with each additional oz/day of fruit drinks: $\beta = -0.01$ (SE = 0.01), $P = 0.38$ soda: $\beta = -0.01$ (SE = 0.02), $P = 0.50$	Adjusted for age, sex, and energy, as well as sociodemographic variables ethnicity, residence, level of poverty, maternal education, and birthweight includes non-100% fruit drinks (e.g., lemonade, fruit punch).
Pan 2014	*Odds of incident obesity associated with consumption of three or		Adjusting for child's gender, child's birthweight, age at solid food introduction, breastfeeding

Table 2A. Continued

Author/year	Results not controlled for total energy	Results controlled for total energy	Covariates
	more SCBs/week compared to no SSBs OR = 2.00 (CI: 1.02, 3.90)		duration, maternal age, maternal race/ethnicity, maternal education, marital status, income-to-poverty ratio, and pre-pregnancy weight status.
Sichieri 2013	*ΔBMI with each additional SCB/day B = 0.11 (0.03, 0.25)		Age, sex, physical activity, intervention and mutually adjusted screen time (computer and television) in hours/day.
Striegel-Moore 2006		*ΔBMI with each 100 g/day of SCB (soda) $\beta = 0.011$ (SE = 0.005) $P < 0.05$	Site, race, intake of calories, other beverages.
Tam 2006	*Soft drink/cordial consumption higher among those who gained or remained overweight versus those who lost weight or remained normal weight $P = 0.005$		No adjustments.
Weijs 2011	*ΔBMIz with each additional 1% of total energy intake from SCBs $\beta = 0.044$ (CI: 0.008, 0.080) $P = 0.016$	ΔBMIz with each additional 1% of total energy intake from SCBs $\beta = 0.055$ (CI: −0.005, 0.115) $P = 0.070$	Animal protein, plus sex, infant age, infant body weight, breastfed at time of assessment, SES. Energy-adjusted model also includes maternal overweight, physical activity in hours per week, and energy intake at age 8 years in kcal/day.
Welsh 2005	Odds ratio of incident obesity among those normal weight at baseline with 1-<2, 2-<3, and ≥3 versus <1 serving SCB/day OR = 1.5 (CI: 0.9, 2.4), 1.4 (CI: 0.8, 2.2), 1.2 (CI: 0.8, 2.0), respectively	OR of incident obesity among those normal weight at baseline with 1-<2, 2-<3, and ≥3 versus <1 serving SCB/day OR = 1.5 (CI: 0.9, 2.4), 1.4 (CI: 0.8, 2.3), 1.3 (CI: 0.8, 2.1), respectively	Age; gender; race/ethnicity; birthweight; and intake of high-fat foods, sweet foods, and with and without total calories.
Wheaton 2015	Relative risk for normal weight at baseline becoming overweight at follow-up with SSB consumption versus no consumption RR = 0.97 (SE = 0.05) $P = 0.57$		Age, sex. ethnicity, socioeconomic position, mother's and father's BMI.
Wijga 2010	Adjusted odds of overweight or obesity among high versus low to moderate SCB consumers OR = 0.91 (CI: 0.44, 1.88)		Gender, birthweight, breastfeeding, fast-food consumption, snack consumption, sports club, active transport to school, playing outside, screen time, maternal education, maternal overweight.
Zheng (*J Hum Nutr Diet*) 2015	*ΔBMIz with each additional 100 g/day of SCB $\beta = 0.08$ (SE = 0.03) $P = 0.02$	*ΔBMIz with each additional 100 g/day of SCB $\beta = 0.10$ (SE = 0.03) $P = 0.003$	Adjusted for age, gender, BMIz score at age 8 years, Socioeconomic Index for Area scores, maternal age at birth, parental education level, parental countries of birth, maternal age at birth, presence of gestational diabetes, breastfeeding characteristics, pubertal status and Childhood Asthma Prevention Study randomization group and with and without total energy intake.
Zheng (*Eur J Nutr*) 2015	*ΔBMIz with each additional 100 g/day of SCB $\beta = 0.06$ (SE = 0.03) P = 0.04	ΔBMIz with each additional 100 g/day of SCB $\beta = 0.05$ (SE = 0.03) $P = 0.10$	Baseline age, BMIz score, sex, intervention allocation, physical activity, whether parents were divorced, number of siblings living with the child, annual income, maternal and paternal educational levels and maternal pre-pregnancy overweight. With and without total energy intake.

Table 2A. Continued

Author/year	Results not controlled for total energy	Results controlled for total energy	Covariates
Zheng 2014	ΔBMI among those whose SCB consumption increased versus remained the same $\beta = 0.91$ (SE = 0.57) $P = 0.09$	ΔBMI among those whose SCB consumption increased versus remained the same $\beta = 1.00$ (SE = 0.59) $P = 0.11$	Age, gender, BMI/WC/S4SF, SES, pubertal status and physical activity at age 15, with and without total energy intake at age 15.

*Statistically significant positive result.

Studies with change-over-change analyses

Only one study evaluated change in SCB consumption and change in central adiposity over the same time period in children under age 12, and that study demonstrated a statistically significant positive association (47).

Table 3B summarizes the frequency of the included studies with a positive association between SCB consumption and central adiposity, considering risk of bias assessment and study design features that could potentially be biasing or confounding the results.

Association between fruit juice consumption and total adiposity in children under age 12

Fifteen studies addressed the association between fruit juice exposure and total adiposity in children under age 12 (Table 4A). Five out of 11 studies that were uncontrolled for total energy demonstrated a statistically significant positive association. None of the eight studies that were controlled for total energy had statistically significant results. The results of the two-tailed sign test for the 15 studies were 12 with a statistically significant positive association and 3 with a negative association, $P = 0.0352$ (two tailed).

Change over change analyses

Four studies evaluated change in fruit juice consumption and change in total adiposity over the same time period in children under age 12. One found an association between change in juice consumption and change in adiposity (46), and 3 found no association (9,54,61). Among the 11 studies that did not address change over change, 4 demonstrated an association between central adiposity and SCB consumption (49,55,59,72).

Table 4B summarizes the frequency of the included studies with a positive association between fruit juice consumption and total adiposity, considering risk of bias assessment and study design features that could potentially be biasing or confounding the results.

Association between fruit juice consumption and central adiposity in children under age 12

Two studies addressed the association between fruit juice consumption and central adiposity in children under age 12, and neither found an association (Table 5). Both studies presented data both controlled and not controlled for total energy and demonstrated concordance among both models and total adiposity.

Table 2B Subgroup Analyses of Statistically Significant Positive Association Between SCB Intake and Total Adiposity (With or Without Controlling for Total Energy Intake) in Children Under Age 12

Risk of bias	
Low risk of bias	7 out of 12 studies (58%) (40,48,51-53,61,68)
Moderate or high risk of bias	12 out of 19 studies (63%) (12,46,47,50,54,55,60-63,67,71,72)
Study size	
≥250 subjects	14 out of 22 studies (64%) (12,46,48,52-54,56,60,61,63,68,71,72,77)
<250 subjects	4 out of 9 studies (44%) (47,50,62,67)
≥100 subjects	18 out of 29 studies (62%) (12,46-48,50,52-54,56,60-63,67,68,71,72,77)
<100	0 out of 2 studies
Control for age, sex, and physical activity	
Controlled for all 3 factors	7 out of 11 studies (64%) (12,47,50,63,67,71,72)
Controlled for 0-2 factors	11 out of 20 studies (55%) (46,48,52-54,56,60-62,68,77)
United States versus non-United States	
United States	6 out of 12 studies (58%) (40,50,56,61,68,77)
Non-United States	13 out of 19 studies (68%) (12,46-48,52-54,60,62,63,67,71,72)

Table 3A Data Abstraction for Association Between Sugar-Containing-Beverage Consumption and Central Adiposity

Author/year	Results not controlled for total energy	Results controlled for total energy	Confounders
Bigornia 2015	*Change in waist circumference (WC) associated with increased sugar-containing beverage (SCB) consumption (serving/day) $\beta = 0.097$ (SE = 0.14) $P < 0.001$		Sex, age, height, adiposity, physical activity at age 13 years; pubertal stage at age 13 years; maternal overweight/obesity status; maternal education; dieting at age 1 year; change in fruit juice, fruit and vegetable, and total fat intakes from ages 10 to 13 years.
Cantoral 2016	*Unadjusted odds ratio (OR) of WC >90th percentile for those in the third tertile compared to first tertile of SCB consumption OR = 2.29 (95% CI 1.01-5.19)	*Adjusted OR of WC >90th percentile for those in the third tertile compared to first tertile of SCB consumption OR = 2.70 (95% CI 1.03-7.03)	Age at introduction of sugar-sweetened beverages (SSBs), sex, age, TV watching, physical activity, non-SSB total energy intake, breastfeeding up to age 12 months, maternal obesity at 12 months postpartum.
De Ruyter 2012	*Change in WC in sugar-free beverage group versus sugar beverage group Mean difference: −0.69 (−1.22 to −0.17) $P = 0.01$		No confounders because was a true randomized controlled trial; however, not controlled for beverage consumption outside of school.
Feng 2016	Change in waist circumference with daily SCB intake $\beta = 0.01$ (+/− 0.01) *P*-value NS		Group membership, parents' education and acculturation, family income, family meals, child gender and age at baseline, child fast food intake and daily TV time, and home availability of SSBs.
Fiorito 2009	*Association of SCB (servings/day) with increased WC $P < 0.05$		Gender, sex, physical activity were controlled in the study, but not in the relevant data for this systematic review.
Zheng 2014	*Δ WC (cm) with increase in SCB consumption, $\beta = 2.72$ (SE = 1.53), $P = 0.04$	Δ WC (cm) with increase in SCB, $\beta = 3.25$ (SE = 1.53), $P = 0.07$	Age, gender, body mass index/WC/S4SF, socioeconomic status, pubertal status, and physical activity at age 15, with and without total energy intake at age 15.

*Statistically significant positive result.

Association between SCB or juice consumption and total and central adiposity in children under age 5

Eleven studies evaluated total adiposity, with five having SCBs as the exposure, five having only juice as the exposure, and one having both (Table 6A and 6B). None of these studies evaluated central adiposity. Five out of six studies that addressed SCB exposure and total adiposity and were uncontrolled for total energy demonstrated a statistically significant positive association (Table 6A). One of these studies (Du Bois et al.) (47) demonstrated that the positive association remained and another (Weijs et al.) (66) that the association

Table 3B Subgroup Analyses of Statistically Significant Positive Association Between SCB Consumption and Central Adiposity (With or Without Controlling for Total Energy intake) in Children Under Age 12

Risk of bias	
Low risk of bias	1 out of 1 study (100%) (65)
Moderate or high risk of bias	4 out of 5 studies (80%) (12,47,50,71)
Study size	
≥250 subjects	2 out of 3 studies (67%) (12,71)
<250 subjects	2 out of 3 studies (100%) (47,50,65)
≥100 subjects	5 out of 6 studies (83%) (12,47,50,65,71)
<100	No studies had <100 subjects
Control for age, sex, and physical activity	
Controlled for all 3 factors	5 out of 6 studies (83%) (12,47,50,65,71)
Controlled for 0-2 factors	No studies controlled for only 0-2 of these factors
US versus non-US	
United States	2 out of 3 studies (67%) (50,71)
Non-United States	3 out of 3 studies (100%) (12,47,65)

Table 4A Data Abstraction for Association Between Juice Consumption and Total Adiposity

Author/year	Results not controlled for total energy	Results controlled for total energy	Confounders
Dong 2015	*Estimated 3-year excess weight gain of 35 g per 100 g increase in daily juice intake $P < 0.05$		Fat spread, nuts, coated poultry, potato chips, coated fish, processed meats, uncoated fish, French fries and roasted potatoes, meats, uncoated poultry, canned fruit, eggs, desserts and sweets, full-fat milk, low-fat milk, sugar-sweetened beverages (SSBs), fruit, potatoes not cooked in oil, juices, diet soda, vegetables, yogurt, cheese, refined grains, non-high-fiber breakfast cereal, whole grains, high fiber cereal.
Faith 2006	*Association of change in juice consumption with excess weight gain Change-over-change model $\beta = 0.005$ (SE = 0.002) $P < 0.01$		Baseline body mass index standard deviation (BMIz), gender, race, intake of potatoes, carrots, vegetables, fruits, milk whole milk, parental behaviors of tried more (TM) fruits, TM vegetables, limit how much eaten, finish dinner before dessert.
Guerrero 2016	Body mass index (BMI) change with any versus no juice $\beta = -0.101$ (SE = 0.053) $P > 0.05$		Age, sex, race, birthweight, N parents in household, poverty status, maternal education, acculturation, breastfeeding history, fast food consumption, fruit consumption, vegetables consumption.
Lee 2015	Δ BMIz with each additional teaspoon of sugar consumed in fruit juice $\beta = -0.0001$ [confidence interval (CI): −0.002, 0.002] $P = 0.95$	BMIz-score change with each additional teaspoon of sugar consumed $\beta = -0.001$ (CI: −0.003, 0.002) $P = 0.60$	Adjusted for race, initial age, initial BMI, initial waist circumference (WC), initial puberty stage, parents' income, parents' education, dieting status, initial and change in physical activity, change in height and baseline sugars, initial and change in grams of fiber, percentage of energy from fat and percentage of energy from other carbohydrates. Model 3 additionally adjusted for initial and change in total energy intake.
Muckelbauer 2016	Δ BMI with each additional glass of juice $\beta = 0.01$ (CI: −0.01, 0.03)		Baseline BMI, baseline and change in consumption of all beverage categories, age, sex, migrational background, study arm, and follow-up duration.
Newby 2004		Δ BMI with each additional oz/day of fruit juice: $\beta = 0.01$ (SE = 0.00) $P = 0.20$	Adjusted for age, sex, and energy, as well as sociodemographic variables ethnicity, residence, level of poverty, maternal education, and birthweight. Includes non-100% fruit drinks (e.g., lemonade, fruit punch).
Shefferly 2016	*Δ BMIz with <1 serving/day, $\beta = 0.030$ (SE = 0.037), compared to Δ BMIz with juice ≥1 serving day, $\beta = 0.282$ (SE = 0.028) $P = 0.0003$		Sex, race, socioeconomic status (SES) and maternal BMI, baseline BMI z-score.
Sichieri 2013	*Δ BMIz with each additional fruit juice, $\beta = 0.15$ (CI: 0.10, 0.20)		Age, sex, physical activity, intervention, and mutually adjusted screen time (computer and television) in hours/day.
Skinner 2001		Δ BMI with each additional oz juice/day $\beta = -0.057$ ($P = 0.99$)	Height and BMI at age 24 months, gender, energy intake, parents' heights or BMI.
Skinner 1999	Among those who consumed <12 oz of juice, BMI = 16.3 Among those who consumed ≥12 oz of juice, BMI = 16.4 $P = 0.42$		Models included interview, interview/juice category interaction, child's age, gender, age/gender interaction, and maternal height and BMI.

Table 4A. Continued

Author/year	Results not controlled for total energy	Results controlled for total energy	Confounders
Sonneville 2015	*Compared to non-consumers, Δ BMI among those consuming 1-7 oz juice, $\beta = 0.08$ (CI:−0.05, 0.20); 8-15 oz juice, $\beta = 0.23$ (CI 0.07, 0.39); and ≥16 oz juice, $\beta = 0.36$ (CI: 0.08-0.64) $P = 0.01$	Compared to non-consumers, Δ BMI among those consuming 1-7 oz juice, $\beta = 0.07$ (CI: −0.06, 0.21); 8-15 oz juice, $\beta = 0.23$ (CI 0.05, 0.40); and ≥16 oz juice, $\beta = 0.27$ (CI: −0.05-0.59) $P = 0.05$	Adjusted for maternal age, education, pre-pregnancy BMI, household income, and child age, sex, race/ethnicity, and weight-for-length z-score at age 1 year, juice and water intake at age 1. Calorie intake at age 3 years added to energy adjusted model.
Striegel-Moore 2006		Δ BMI with each 100 g/day of fruit juice $\beta = 0.005$ (SE = 0.007) *P*-value not stated	Site, race, intake of calories, other beverages.
Welsh 2005		Odds ratio (OR) of incident obesity among those normal weight at baseline with 1-<2, 2-<3, and ≥3 versus <1 serving fruit juice/day, OR = 1.1 (CI: 0.8, 1.5), 1.0 (CI: 0.7, 1.4), 1.2 (CI: 0.8, 1.7), respectively	Age; gender; race/ethnicity; birthweight; and intake of high-fat foods, sweet foods, and with and without total calories.
Zheng (*J Hum Nutr Diet*) 2015	Δ BMIz with each additional 100 g fruit juice/day, $\beta = 0.07$ (SE = 0.05) $P = 0.15$	Δ BMIz with each additional 100 g fruit juice/day, $\beta = 0.07$ (SE = 0.05) $P = 0.12$	Adjusted for age, gender, BMIz-score at age 8 years. Socioeconomic Index for Area scores, maternal age at birth, parental education level, parental countries of birth, maternal age at birth, presence of gestational diabetes, breastfeeding characteristics, pubertal status and Childhood Asthma Prevention Study randomization group and with and without total energy intake.
Zheng (Nutrition) 2015	Δ BMIz with each additional 100 g/day of fruit juice, $\beta = 0.02$ (SE = 0.03) $P = 0.39$	Δ BMIz with each additional 100 g/day of fruit juice, $\beta = 0.03$ (SE = 0.03) $P = 0.35$	Baseline age, sex, baseline BMIz/WC/S4SF, physical activity, SES, and pubertal status with and without total energy.

* Statistically significant positive result.

Table 4B Subgroup Analyses of Statistically Significant Positive Association Between Fruit Juice Consumption and Total Adiposity (With or Without Controlling for Total Energy Intake) in Children Under Age 12

Risk of bias	
Low risk of bias	2 out of 5 studies (40%) (55,59)
Moderate or high risk of bias	3 out of 10 studies (30%) (46,49,72)
Study size	
≥250 subjects	5 out of 12 studies (42%) (46,49,55,59,72)
<250 subjects	0 out of 3 studies
≥100 subjects	5 out of 14 studies (36%) (46,49,55,59,72)
<100	0 out of 1study
Control for age, sex, and physical activity	
Controlled for all 3 factors	1 out of 3 studies (72)
Controlled for 0-2 factors	5 out of 12 studies (33%) (46,49,55,59)
United States versus non-United States	
United States	4 out of 10 studies (40%) (46,49,55,59)
Non-United States	1 out of 5 studies (20%) (72)

Table 5 Data Abstraction for Association Between Juice Consumption and Central Adiposity

Author/year	Results not controlled for total energy	Results controlled for total energy	Confounders
Lee 2015	Δ waist circumference (WC) among normal weight with each tsp of added sugar from fruit juice $\beta = 0.185$mm (CI: −0.064, 0.434) $P = 0.15$	Δ WC among normal weight with each tsp of added sugar from fruit juice $\beta = 0.127$ (−0.0127, 0.381) $P = 0.33$	Adjusted for race, initial age, initial body mass index (BMI), initial WC, initial puberty stage, parents' income, parents' education, dieting status, initial and change in physical activity, change in height and baseline sugars, initial and change in grams of fiber, percentage of energy from fat, and percentage of energy from other carbohydrates. Model 3 additionally adjusted for initial and change in total energy intake.
Zheng (*Nutrition*) 2015	Δ WC with each 100 g/day of fruit juice $\beta = -0.01$ (SE = 0.22) $P = 0.59$	Δ WC with each 100 g/day of fruit juice $\beta = -0.01$ (0.23) $P = 0.96$.	Baseline age, sex, baseline BMI standard deviation (BMIz)/WC/S4SF, physical activity, socioeconomic status, and pubertal status with and without total energy.

*Statistically significant positive result.

Table 6A Data Abstraction for Association Between Sugar-Containing-Beverage Consumption and Total Adiposity in Children Under Age 5

Author/year	Results not controlled for total energy	Results controlled for total energy	Confounders
De Boer, 2013	*Greater increase in body mass index standard deviation (BMIz) among those consuming of SCB/day compared to those consuming less. $P < 0.05$		Adjusted for Race/ethnicity, socioeconomic status (SES)
Dubois 2007	*Association of being overweight and regular sugar-containing beverage (SCB) consumption between meals Odds ratio (OR) 2.363 [95% confidence interval (CI) 1.105, 5.054]	*OR for association of being overweight and regular sugar-sweetened beverage (SSB) consumption between meals: 2.356 (95% CF 1.030-5.390)	Sex, maternal smoking during pregnancy, physical activity, birthweight, income level, n of overweight parents, consumption of fruits and vegetables, grain products, milk products, meat and alternatives.
Guerrero 2016	*Association of "any soda" with BMI trajectory level ß = 0.138 (SE = 0.037) $P < 0.01$		Age, sex, race, birthweight, N parents in household, poverty status, maternal education, acculturation, breastfeeding history, fast-food consumption, fruit consumption, vegetables consumption.
Pan 2014	*Adjusted OR of obesity at age 6 years among infants who consumed three or more SSBs/week ($n = 71$) compared to no SSBs ($n = 990$): 2.00 (95% CI: 1.02-3.90)		Adjusting for child's gender, child's birthweight, age at solid food introduction, breastfeeding duration, maternal age, maternal race/ethnicity, maternal education, marital status, income-to-poverty ratio, and pre-pregnancy weight status.
Weijs 2011	*ΔBMIz with each additional 1% of total energy intake from SCBs $\beta = 0.044$ (CI: 0.008, 0.080) $P = 0.016$	ΔBMIz with each 1% of total energy intake from SCBs $\beta = 0.055$ (CI: −0.005, 0.115) $P = 0.070$	Animal protein, plus sex, infant age, infant body weight, breastfed at time of assessment, SES. Energy-adjusted model also includes: maternal overweight, physical activity in hours per week, and energy intake at age 8 years in kcal/day.
Welsh 2005	Odds ratio of incident obesity among those normal weight at baseline with 1-<2, 2-<3, and ≥3 versus <1 serving SCB/day, OR = 1.5 (CI: 0.9, 2.4), 1.4 (CI: 0.8, 2.2), 1.2 (CI: 0.8, 2.0), respectively	OR of incident obesity among those normal weight at baseline with 1-<2, 2-<3, and ≥3 versus <1 serving SCB/day, OR = 1.5 (CI: 0.9, 2.4), 1.4 (CI: 0.8, 2.3), 1.3 (CI: 0.8, 2.1), respectively	Age; gender; race/ethnicity; birthweight; and intake of high-fat foods, sweet foods, and with and without total calories.

*Statistically significant positive result.

Table 6B Data Abstraction for Association Between Juice Consumption and Total Adiposity in Children Under 5

Author/year	Results not controlled for total energy	Results controlled for total energy	Confounders
Faith 2006	*Association of change in juice consumption with excess weight gain Change-over-change model $\beta = 0.005$ (SE = 0.002) $P < 0.01$		Baseline body mass index standard deviation (BMIz), gender, race, intake of potatoes, carrots, vegetables, fruits, milk whole milk, parental behaviors of tried more (TM) fruits, TM vegetables, limit how much eaten, finish dinner before dessert.
Shefferly 2016	*Δ BMIz with juice <1 serving/day, $\beta = 0.030$ (SE = 0.037) compared to Δ BMIz with juice ≥1 serving/day, $\beta = 0.282$ (SE = 0.028) $P = 0.0003$		Sex, race, socioeconomic status and maternal BMI, baseline BMIz-score.
Skinner 2001		Δ BMI with each additional oz juice/day $\beta = -0.057$ ($P = 0.99$)	Height and BMI at age 24 months, gender, energy intake, parents' heights or BMI.
Skinner 1999	Among those who consumed <12 oz of juice, BMI = 16.3 Among those who consumed ≥12 oz of juice, BMI = 16.4 $P = 0.42$		Models included interview, interview/juice category interaction, child's age, gender, age/gender interaction, and maternal height and BMI.
Sonneville 2015	*Compared to non-consumers, Δ BMI among those consuming 1-7 oz juice, $\beta = 0.08$ [confidence interval (CI):−0.05, 0.20]; 8-15 oz juice, $\beta = 0.23$ (CI 0.07, 0.39); and ≥16 oz juice, $\beta = 0.36$ (CI: 0.08-0.64) $P = 0.01$	*Compared to non-consumers, Δ BMI among those consuming 1-7 oz juice, $\beta = 0.07$ (CI:−0.06, 0.21); 8-15 oz juice, $\beta = 0.23$ (CI 0.05, 0.40); and ≥16 oz juice, $\beta = 0.27$ (CI: −0.05 to 0.59) $P = 0.05$	Adjusted for maternal age, education, pre-pregnancy BMI, household income, and child age, sex, race/ethnicity, and weight-for-length z-score at age 1 year, juice and water intake at age 1 year. Calorie intake at age 3 years added to energy-adjusted model.
Welsh 2005		Odds ratio (OR) of incident obesity among those normal weight at baseline with 1-<2, 2-<3, and ≥3 versus <1 serving fruit juice/day, OR = 1.1 (CI: 0.8, 1.5), 1.0 (CI: 0.7, 1.4), 1.2 (CI: 0.8, 1.7), respectively	Age; gender; race/ethnicity; birthweight; and intake of high-fat foods, sweet foods, and with and without total calories.

* Statistically Significant Positive Result.

no longer reached statistical significance when the analysis was also controlled for total energy.

Three of the four studies that addressed fruit juice exposure and total adiposity and were uncontrolled for total energy demonstrated a statistically significant positive association (Table 6B). One out of three studies that addressed fruit juice exposure and total adiposity and were controlled for total energy demonstrated a statistically significant positive association.

Table 6C summarizes the results of the analyses of all studies that demonstrated a statistically significant positive association between SCB or fruit juice consumption and central adiposity in children under age 5 stratified by study design features that could potentially be biasing or confounding the results.

Discussion

The general trend of the evidence supports the results of previous reviews among older children and adults and suggests that SCB consumption is associated with total and central adiposity in children under age 12. The majority of studies examining fruit juice consumption and total adiposity demonstrated a statistically significant positive association only in studies among young children, those under age 5. No evidence is available to assess the impact on central adiposity in this age group. Among children under age 12, the majority of studies did not demonstrate a statistically significant positive association with fruit juice consumption. However, results of the two-tailed sign, which takes into account the direction of the association regardless of whether the results were statistically significant, suggests that there may be an association between fruit juice consumption and total adiposity in children under age 12.

Due to substantial methodological heterogeneity in the included studies (study design, age group, exposure, outcome measurements, covariates, statistical analyses) meta-analyses could not be performed. Therefore, our systematic review relied on a count of studies with positive versus negative results. While this is a methodological weakness given that

Table 6C Subgroup Analyses that Demonstrated a Statistically Significant Positive Association Between Sugar-Containing-Beverage or Fruit Juice Consumption and Total Adiposity (With or Without Controlling for Total Energy Intake) in Children Under Age 5

Risk of bias	
Low risk of bias	5 out of 5 studies (100%) (47,48,55,59,68,77)
Moderate or high risk of bias	3 out of 6 studies (50%) (49,56,57)
Study size	
≥250 subjects	7 out of 8 studies (88%) (48,49,55,56,59,68,77)
<250 subjects	1 out of 3 studies (33%) (67)
≥100 subjects	8 out of 10 studies (80%) (48,49,55,56,59,67,68,77)
<100	0 out of 1 study
Control for age, sex, and physical activity	
Controlled for all 3 factors	1 out of 1 study (100%) (67)
Controlled for 0-2 factors	7 out of 10 studies (100%) (48,49,55,56,59,68,77)
US versus non-US	
United States	6 out of 9 studies (67%) (49,55,56,59,68,77)
Non-United States	2 out of 2 studies (100%) (48,67)

statistical significance is used to define "positive" and "negative" studies and differential weights for each study is not taken into account, Cochrane guidelines acknowledge that such vote counting is necessary in instances where standard meta-analytical methods cannot be performed (75). Another limitation was the inclusion of only studies published in English. This decision was made due to difficulty in screening and assessing non-English publications. We were also not able to assess publication bias because of the essentially qualitative nature of this systematic review. However, it is reassuring that multiple studies both supporting and not supporting an association between SBC and obesity were identified. Another limitation is sample size variability in the included studies, as studies with very large sample size could have statistically significant results that are not clinically relevant. We were not able to evaluate clinically relevant effect sizes since a meta-analysis was not possible. Finally, we included only the results of the main analysis from each study. Results of analyses that were further stratified by baseline weight were not included, and it is possible that SCB consumption may have greater impact on those with different weight and obesity status at baseline.

The highest level of evidence that could be anticipated for our clinical question is a double blinded RCT. Only one such study met the inclusion criteria for this systematic review (71). While this RCT was nearly 2 years in duration, due to limitations related to sample selection and lack of blinding of participants, it was judged to be at high risk of bias. Even though the majority of studies included in this systematic review received a moderate risk of bias, the studies varied greatly, with differences in methodology such that meta-analysis was not feasible. Another weakness was that several studies evaluated exposure during either one or multiple observations at baseline, with some assuming that the exposure level extended for the duration of the study and others calculating an average exposure from longitudinal observations. Because of these concerns, our confidence in the synthesis of the available evidence is low. Given the increase in prevalence of obesity among children and the increase in SCB consumption, the dearth of quality evidence highlights the need for further research using comparable methods.

In addition to exposure determination, several methodological factors could potentially influence the results of the included studies, such as number of subjects, location (United States versus non-United States), risk of bias, subjects' ages, duration of the study, and length of follow-up. There was substantial variation in the definitions of SCB used between studies as well as variation in the dietary-assessment methods used. Additionally, almost all of included studies were retrospective and had small numbers of subjects in the cohort used for the analysis compared to the original cohort. The majority of studies did not control for the three priority factors likely to influence the results: age, sex, and physical activity level.

We evaluated the hypothesis that an association with central adiposity is more likely to be seen than with total adiposity. However, we did not find this to be the case. Among the six studies that evaluated both central and total adiposity with either SCB or fruit juice, all had complete concordance among the results. Three of the SCB studies demonstrated an association with total and central adiposity (47,49,71), where as one did not (45). The two studies that analyzed both total and central adiposity for fruit juice did not demonstrate associations (55,64).

We also evaluated the role of total energy intake as a possible meditator in the association between SCB or 100 percent fruit juice consumption and adiposity by comparing the likelihood of positive results among studies that controlled for total energy compared to those that did not. Regardless of the beverage type, or the measure of adiposity, we found that studies were more likely to be positive when not controlled for total energy than when they were. This suggests that total calorie intake does play a role in increasing the risk of obesity associated with sugary beverage consumption.

Given the small magnitude of effect in the studies that did demonstrate a statistically significant positive association, their clinical relevance is unclear. These results may be an underestimation of a true effect due to difficultly in measuring the exposure and the outcome or due to confounding not adequately addressed in the analysis. It is also possible that these results represent the true effect and that, within the range of usual consumption of children at this age, the effect of SCBs is minimal.

There are several published systematic reviews that address the association of the consumption of SCBs, sometimes defined as SSBs or nutritively sweetened beverages, and adiposity in children and adults (7,8,24-27,29,30,34-36). None of these systematic reviews addressed children under age 12 specifically, but some did address children and adolescents of varying age ranges. Overall, the conclusions of the systematic reviews varied, with five systematic reviews concluding that there is an association between SCB consumption and total adiposity measures (8,9,27,30,34), four systematic reviews that found conflicting evidence or could not come to a conclusion (24,25,29,34), and two systematic reviews that found no association (35,36).

The Gibson (24) systematic review examining the etiology of SSB consumption in promoting excess body weight in adults or children found that about half of the studies found a statistically significant positive association between SSB consumption and BMI, weight, adiposity, or weight gain, but most studies suggested that the effect of SSB consumption is small except in susceptible individuals or at high levels of consumption. The Perez-Morales et al. (29) systematic review specifically focused on SSB consumption before age 6, and concluded that there was an overall trend of an association between SSB consumption before age 6 and increased weight, BMI, or waist circumference, but with overall inconsistent results. The Trumbo (34) systematic review concluded that the results from observational studies that were adjusted for energy intake and physical activity were inconsistent, and evidence for an association between SSB consumption intake obesity risk was inconsistent when adjustment for energy balance was made.

Keller et al. (25) conducted a synthesis of systematic reviews and found that, although the majority of systematic reviews demonstrate an association between SSB consumption and weight gain and obesity, more recent and well-conducted meta-analyses had discrepant results.

Two systematic reviews with meta-analyses of RCTs have been conducted, neither of which demonstrated an association between SCB consumption and adiposity (35,36). Forshee et al. (35) concluded that the association between SCB consumption and BMI was near zero, but the results had high heterogeneity, and there were concerns about publication bias, with those studies that do not show a statistically significant result being less likely to be published. Mattes et al. (36) concluded that suggestive, but not conclusive, evidence demonstrate that SCB consumption may contribute to obesity. The results of our systematic review are consistent with this body of evidence.

Conclusion

The evidence suggests that the consumption of SCBs or fruit juice only among children under age 5 is positively associated with total adiposity. For children under age 12, the evidence for SCB is more mixed, but still suggests a possible association with total adiposity and a strong association with central adiposity. The majority of evidence for fruit juice does not suggest an association with either. Due to the variable quality evidence, the mixed results, and small magnitude of effect, robust high-quality RCTs could significantly alter these conclusions. Further research using more consistent exposure and outcome methods and more robust study designs are needed to extend and validate the conclusions of this review.

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