Fruit Juice and Change in BMI: A Meta-analysis

Brandon J. Auerbach, MD, MPH,[a,b] Fred M. Wolf, PhD,[b,c,d] Abigail Hikida, MD,[d,e,f]
Petra Vallila-Buchman, MPH,[g] Alyson Littman, PhD, MPH,[b,e,f] Douglas Thompson, PhD,[h]
Diana Louden, MLib,[i] Daniel R. Taber, PhD, MPH,[g] James Krieger, MD, MPH[a,d,g]

abstract

CONTEXT: Whether 100% fruit juice consumption causes weight gain in children remains controversial.

OBJECTIVE: To determine the association between 100% fruit juice consumption and change in BMI or BMI *z* score in children.

DATA SOURCES: PubMed, Embase, CINAHL, and Cochrane databases.

STUDY SELECTION: Longitudinal studies examining the association of 100% fruit juice and change in BMI measures were included.

DATA EXTRACTION: Two independent reviewers extracted data using a predesigned data collection form.

RESULTS: Of the 4657 articles screened, 8 prospective cohort studies (n = 34 470 individual children) met the inclusion criteria. Controlling for total energy intake, 1 daily 6- to 8-oz serving increment of 100% fruit juice was associated with a 0.003 (95% CI: 0.001 to 0.004) unit increase in BMI *z* score over 1 year in children of all ages (0% increase in BMI percentile). In children ages 1 to 6 years, 1 serving increment was associated with a 0.087 (95% confidence interval: 0.008 to 0.167) unit increase in BMI *z* score (4% increase in BMI percentile). 100% fruit juice consumption was not associated with BMI *z* score increase in children ages 7 to 18 years.

LIMITATIONS: All observational studies; studies differed in exposure assessment and covariate adjustment.

CONCLUSIONS: Consumption of 100% fruit juice is associated with a small amount of weight gain in children ages 1 to 6 years that is not clinically significant, and is not associated with weight gain in children ages 7 to 18 years. More studies are needed in children ages 1 to 6 years.

Departments of [a]Medicine, [b]Epidemiology, [c]Biomedical Informatics and Medical Education, [d]Health Services, and [i]University Libraries, University of Washington, Seattle, Washington; [e]VA Puget Sound Health Care System, Seattle, Washington; [f]Northwest VA Health Services Research & Development Center of Excellence, Seattle, Washington; [g]Healthy Food America, Seattle, Washington; and [h]Thompson Research Consulting, Chicago, Illinois

Dr Auerbach conceptualized and designed the study, acquired the data (performed the systematic review), performed the meta-analysis, and led the drafting of the manuscript; Dr Wolf conceptualized and designed the study, supervised the performance of the systematic review and meta-analysis, and revised the article for important intellectual content; Dr Hikida acquired the data (performed the systematic review) and revised the article critically for important intellectual content; Ms Vallila-Buchman conceptualized and designed the study, and drafted the article (substantial parts of the Discussion section); Dr Littman conceptualized and designed the study and critically revised the manuscript for important intellectual content; Dr Thompson substantially contributed to the biostatistical analysis and meta-analysis and critically revised the manuscript for important intellectual content; Ms Louden substantially contributed to the design of the study, acquired the data (designed the search strategy), and drafted the article (substantial parts of the Methods section and Search Strategy section of the Supplemental Materials); Dr Taber substantially contributed to the analysis and interpretation of the data and critically revised the manuscript for important intellectual content; Dr Krieger

To cite: Auerbach BJ, Wolf FM, Hikida A, et al. Fruit Juice and Change in BMI: A Meta-analysis. *Pediatrics.* 2017;139(4):e20162454

Experts have expressed concerns that the high content of naturally occurring sugars in 100% fruit juice may cause negative health effects similar to those of sugar-sweetened beverages.[1,2] The sugars in 100% fruit juice are broken down and absorbed as glucose and fructose and are nutritionally equivalent to the free sugars in sugar-sweetened beverages.[3,4] Since 2001, the American Academy of Pediatrics (AAP) has recommended that no more than half of children's daily fruit servings come from 100% fruit juice. The AAP recommends that children 1 to 6 years old limit fruit juice intake to 4 to 6 oz per day and that children ≥7 years limit intake to 8 to 12 oz per day.[3] The 2015–2020 Dietary Guidelines for Americans (DGA) have endorsed these guidelines by the AAP.[5]

Younger children drink more 100% fruit juice than any other age group and often consume more than is recommended by the AAP and DGA.[6] Almost two-thirds of children drink 100% fruit juice by age 1 year.[7] Almost half of young children 2 to 8 years old are consumers. Among children who drink any 100% fruit juice, mean consumption is 10.6 oz per day among children 2 to 18 years of age and 9.9 oz per day among children 2 to 8 years of age. Almost one-third of children 2 to 6 years old consume >6 oz per day of 100% fruit juice. Only 2% of children 7 to 18 years old exceed AAP/DGA recommendations (consuming >12 oz per day).[7]

Whether 100% fruit juice may cause weight gain and obesity in children is an open question, with individual studies yielding mixed findings.[2,8] One systematic review[9] and 1 meta-analysis[10] concluded that 100% fruit juice consumption was not associated with excess weight in children, but both had limitations. The systematic review by O'Neil and Nicklas[11] had a low score (3/11) on the Assessing the Methodological Quality of Systematic Reviews (AMSTAR) quality rating scale. The meta-analysis by Crowe-White and colleagues[10] had an intermediate AMSTAR score (7/11) and was limited in that only PubMed was searched, 2 large studies from 2015 were not included,[1,12] and 15 of the 16 included studies were cross-sectional, which are liable to confounding and reverse causation.[13] Crowe-White and colleagues[10] acknowledged receiving funding from the Juice Products Association and PepsiCo, which raises concerns about influence on the part of these funders. An updated, methodologically rigorous synthesis of the data on the effects of 100% fruit juice on children's weight is needed.

We therefore performed a systematic review and meta-analysis of longitudinal studies that investigated the association between 100% fruit juice consumption and change in BMI or BMI *z* score (Table 1).

TABLE 1 Population-Intervention-Comparison-Outcome-Time Summary Statement

Study population	Children ages 1 to 18 y, not malnourished or hospitalized
Intervention/exposure	Consumption of 100% fruit juice
Comparison	No consumption of 100% fruit juice
Outcomes	Change in BMI or BMI *z* score
Time	Studies published through December 31, 2015
Setting	Children in developed countries
Study design	Any study design with longitudinal data and at least 6 mo of follow-up

METHODS

Literature Search

This study complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[14] The methods were prespecified and documented in a protocol (PROSPERO registration number: CRD42016032868).[15]

We conducted primary systematic literature searches using combinations of keywords, including juice, beverages, fruit, weight, and weight gain (see the Search Strategy section in the Supplemental Materials for the full list). We used broad keywords and MeSH terms to err on the side of inclusiveness. We searched 4 databases: PubMed (Medline), Embase, CINAHL, and the Cochrane Central Register of Controlled Trials (CENTRAL). We searched each database for peer-reviewed articles available in English from its inception through December 31, 2015.

Study Selection

Studies were included if they met the following criteria: (1) the exposure variable included 100% fruit juice; (2) outcomes included change in BMI or BMI *z* score; (3) the study design was a randomized controlled trial, other controlled experimental study, or cohort study; (4) the article was in English in a peer-reviewed journal; (5) the population was human subjects ages 1 to 18 years old; and (6) the follow-up time was at least 6 months. The type of dietary assessment instrument was not an inclusion criterion. Studies that measured baseline 100% fruit juice consumption or change in 100% fruit juice consumption were included.

Studies were excluded if they met any of the following criteria: (1) the juice exposure variable was not limited to 100% fruit juice; (2) the study design was cross-sectional or narrative review; (3) the study population was hospitalized patients or malnourished subjects. We excluded cross-sectional studies because they are particularly prone to confounding and reverse causation. If >1 article was published on the same subjects, results from only 1 study were included in the analysis so as not to include the same subjects more than once. When multiple articles analyzed the same subjects, we included only the article with the largest number of participants.

Two authors reviewed titles and abstracts and excluded obviously irrelevant manuscripts that did not study fruit, fruit juice, beverages, weight, or BMI. Two authors independently reviewed each potentially eligible study selected for full-text review. Disagreements were resolved by a consensus of all authors. The software program Covidence (Melbourne, Victoria, Australia)was used to track searches and included/excluded articles.[16]

Data Extraction

Two authors abstracted data from the eligible studies using a standard form that included field for eligibility criteria, design features, study population, the number of individuals in each group, and outcomes related to 100% fruit juice consumption. We abstracted multivariable-adjusted regression coefficients and corresponding SDs, SEs, and 95% confidence intervals (CIs) for the association between 100% fruit juice consumption and change in BMI or BMI *z* score. Because total energy may mediate the association between 100% fruit juice and weight change,[17] when possible we extracted estimates with and without adjustment for total energy. If a study did not report the SD, SE, or 95% CI, we imputed this value using methods referenced in the Cochrane Handbook for Systematic Reviews of Interventions.[18]

Data Synthesis

Our primary association of interest was the change in BMI or BMI *z* score per 1 serving per day increase of 100% fruit juice consumed during the time period specified in each study. The current AAP 100% fruit juice guidelines[3] define 1 serving size of 100% fruit juice as 6 oz, whereas the 2015–2020 DGA[5] define 1 serving of 100% fruit juice as 8 oz. Therefore, we counted 1 serving of 100% fruit juice as consumption of 6 to 8 oz.

We performed analyses both with and without the application of scaling factors to reported regression coefficients to standardize 1 serving of 100% fruit juice to 6 to 8 oz. across studies. We followed a method similar to that described by Malik et al[19] to standardize beverage serving sizes and, for the study by Faith et al,[20] to adjust the reported change in BMI *z* score over 1 month to a change in BMI *z* score over 1 year.

Statistical Analysis

For the meta-analysis, we used means and SDs for the continuous outcomes of change in BMI and BMI *z* score. If a study reported both outcomes, we used BMI *z* score data because 7 of the 8 included studies analyzed this outcome and because BMI *z* score is commonly used by pediatricians. Changes in BMI *z* score of 0.25 to 0.50 U are considered clinically significant in children with respect to weight and cardiometabolic risk.[21,22] In high-risk populations, such as obese adolescents, changes in BMI *z* score as small as 0.09 U may be associated with small changes in cardiometabolic risk.[23] One study[24] did not analyze change in BMI *z* score; for this study, we used the Box-Cox transformation (L), median (M), generalized coefficient of variation (S) (LMS) method to convert the change in BMI to BMI *z* score.[25]

Consistent with previous studies, if included studies reported results for boys or girls, we abstracted the data as reported. We examined the association between 100% fruit juice consumption and BMI *z* score in models that did and did not adjust for energy intake. We performed a prespecified analysis of age subgroups.

I^2 tests of heterogeneity were performed to identify the presence of any between-study variation across pooled studies.[26] We performed meta-analyses using both fixed-effects[27] and random-effects[28] methods. Random-effects results are similar to fixed-effects results when heterogeneity is not substantial ($I^2 < 50\%$). We used fixed-effects models to generate main findings except when substantial heterogeneity was present ($I^2 > 50\%$). In this case, we report results from random-effects models. We calculated 95% CIs for individual study results (if they were not presented in the original articles) and for pooled estimates, with CIs not encompassing 0 indicative of statistical significance ($P < .05$, two-tailed). Stata version 14 (Stata Corp, College Station, TX) was used to conduct the meta-analysis.[29]

Risk of Bias Assessment

Two authors assessed the risk of bias and study quality using the Newcastle-Ottawa Scale for cohort studies.[30] Disagreements in ratings were resolved by discussion between the 2 authors. The Newcastle-Ottawa Scale addresses 3 broad domains: selection of exposed and unexposed subjects, comparability to other cohorts, and outcome assessment. One star was awarded for high-quality features in each area, with a maximum score of 9 stars overall. Two stars are possible in the comparability to other cohorts domain of the Newcastle-Ottawa Scale and must be chosen by investigators for each systematic review. We awarded 1 star for provision of regression coefficients that adjusted for total energy intake and 1 star for age adjustment. Studies with a score >7 were considered high quality, those with a score of 5 to 6 were considered intermediate quality, and those with a score <5

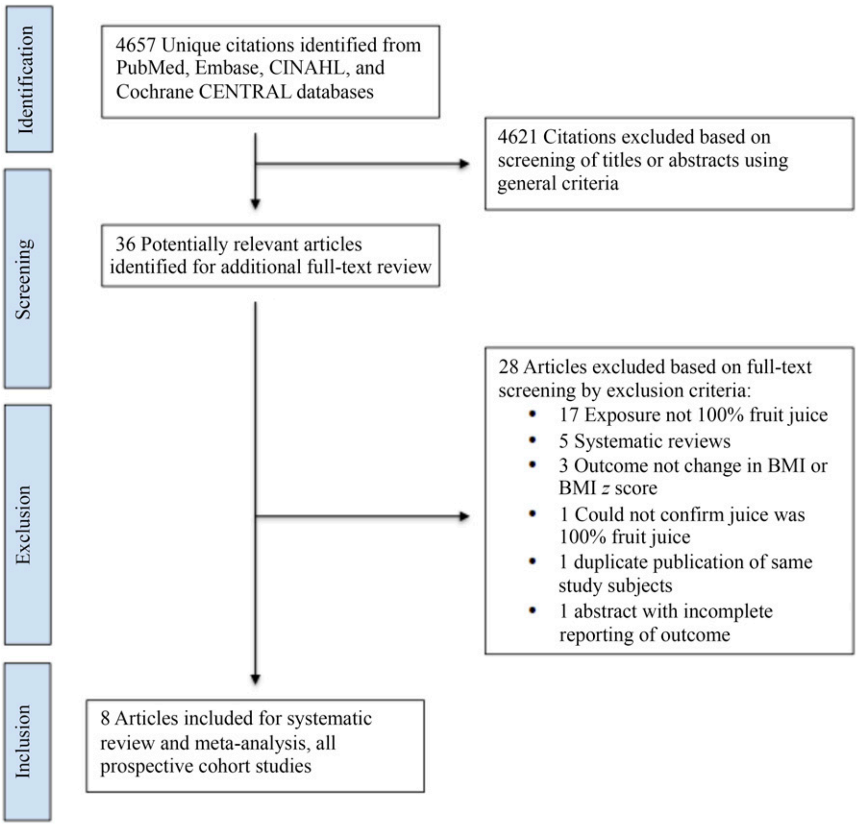

FIGURE 1
Flowchart of studies for inclusion in the systematic review and meta-analysis.

were considered poor quality. A detailed explanation of the domains of study quality is presented in Supplemental Table 5.

RESULTS

Literature Search

Our search strategy identified 4657 unique citations, of which 36 were selected for full-text review after screening titles and abstracts (Fig 1). After full-text review, 28 articles were excluded (Supplemental Table 6), leaving 8 for analysis. Of the 28 excluded studies, 17 were excluded because the exposures did not include 100% fruit juice, 5 because they were systematic reviews, 3 because the outcome was not change in BMI or BMI *z* score, 1 because we could not confirm that the fruit juice was 100% fruit juice,[31] and 1 because it was presented as a conference abstract only, with incomplete outcome reporting of 100% fruit juice consumption.[32] Two studies analyzed the same subjects from the Growing Up Today Study; the smaller of the 2 was excluded.[33]

Study Characteristics

All 8 included studies were prospective cohort studies (Table 2). Six studies were conducted in the United States, 1 was conducted in Germany, and 1 was conducted in the United Kingdom. Baseline ages of study participants ranged from 1 year to 12 years. Study size ranged from 244 to 14 918 subjects, and follow-up duration ranged from 6 months to 10 years. Studies used either food records ($n = 3$) or food frequency questionnaires ($n = 5$) to assess diet. All included studies distinguished between 100% fruit juice and fruit drinks containing <100% fruit drinks. Five studies adjusted for total energy intake, and all studies adjusted for age or presented subgroup analyses by age. Six of the 8 studies assessed 100% fruit juice exposure at baseline only, as opposed to the analyses done by Dong et al[34] and Libuda et al[35] that assessed change in 100% fruit juice intake between 2 time points. The baseline mean BMI was reported or could be calculated in all 8 included studies and ranged from 16.2 ± 2.0 kg/m^2 to 18.6 ± 3.8 kg/m^2. This range of baseline mean BMI falls within the normal weight range of age and sex-adjusted BMI. The baseline mean consumption of 100% fruit juice was reported in 7 studies, and ranged from 3.9 ± 0.2 oz per day to 18.0 ± 7.2 oz per day (Table 2).

Risk of Bias

Study quality and risk of bias are summarized in Supplemental Table 5. Quality scores ranged from 5 to 9 out of a possible score of 9. Five studies had a quality score of ≥7, which we considered high quality. Loss to follow-up was a significant problem across cohorts: only 2 studies had a <20% loss to follow-up.[12,38]

Nonuniform Reported Exposure and Outcome Measures

The 8 included studies reported different 100% fruit juice exposure amounts (range, 1 oz/day to 17 oz/day) and different time periods of change in BMI *z* score (range, 1 month to 6.7 years). The reported time period of change in BMI *z* score was often shorter than the overall follow-up time period of included studies. Because of the small number of included studies, age subgroup analysis was only possible for 2 groups: younger children (baseline age 1–6 years) and older children (baseline age 7–18 years).

Meta-analysis: Younger Children (Baseline Age 1–6 Years)

Three of the 4 studies (combined $n = 9583$) of younger children found statistically significant associations between 100% fruit

TABLE 2 Characteristics of Included Prospective Cohort Studies

Source	Study Population and Location	Sample Size	Mean (± SD) Baseline Age, y	Mean (± SD) Baseline BMI, kg/m^2	Mean (± SD) Baseline Daily 100% Fruit Juice Intake, oz	Mean Follow-up Length	Dietary Assessment	Outcome Assessment	Covariates	Energy adjustment
Dong, 2015[34]	46% boys, 54% girls, Avon Longitudinal Study of Parents and Children, Bristol, United Kingdom	4646	7.5 ± 0.3	16.2 ± 2.0	4.4	6 y	3-d food diary filled out by subject and parent (repeated 3 y apart)	Change in directly measured BMI *z* score per daily serving of 100% fruit juice	Physical activity, pubertal stage, maternal education, consumption of 26 food groups. Sensitivity analyses by age and sex	No
Faith, 2006[20]	53% boys, 47% girls, New York Women, Infants, and Children program data, United States	825	2.5 ± 0.8	16.7	18.0 ± 7.2	2 y	Parental food frequency questionnaire	Change in directly measured BMI *z* score per daily serving of 100% fruit juice	Age, baseline weight-for-height *z* score, food and beverage intake, parental feeding styles, parental feeding attitudes	No
Field, 2003[36]	55% boys, 45% girls, Growing Up Today Study, United States	14 918	11.9 ± 1.6	19.1 ± 3.3	6.8 ± 6.8	3 y	131-item food frequency questionnaire filled out by subject with assistance from parents (repeated annually)	Change in self-reported BMI *z* score per daily serving of 100% fruit juice. Analyzed separately by sex	Age, Tanner stage, baseline BMI *z* score, height change, physical activity, and total energy	Yes
Libuda, 2008[35]	51% boys, 49% girls, Dortmund Nutritional and Longitudinally Designed Study, Dortmund, Germany	235	11.9 ± 1.6	18.3 ± 2.5	6.3 ± 7.5	5 y	3-d weighed diet records by children and parents	Change in directly measured BMI *z* score per daily MJ (240 kcal, or 17 oz) of fruit juice. Analyzed separately by sex	Age, birth weight, years of adolescence, maternal BMI, and total energy	Yes
Newby, 2004[24]	50% boys, 50% girls, North Dakota Women, Infants, and Children program data, United States	1345	2.9 ± 0.7	16.6 ± 1.3	10.7 ± 8.9	8 mo	Parental 84-item food frequency questionnaire at baseline and 6–12 mo later	Change in directly measured BMI per daily ounce of 100% fruit juice consumed	Age, sex, ethnicity, residency, poverty level, maternal education, birth weight, and total energy	Yes

TABLE 2 Continued

Source	Study Population and Location	Sample Size	Mean (± SD) Baseline Age, y	Mean (± SD) Baseline BMI, kg/m^2	Mean (± SD) Baseline Daily 100% Fruit Juice Intake, oz	Mean Follow-up Length	Dietary Assessment	Outcome Assessment	Covariates	Energy adjustment
Shefferly, 2015[1,37]	51% boys, 49% girls, Early Childhood Longitudinal Study-Birth Cohort, United States	8950	2	16.7 ± 2.4	Not reported	3 y	Parental food frequency questionnaire by structured interview at age 2, 4, and 5 y	Change in directly measured BMI *z* score per daily serving (8 oz) of 100% fruit juice	Sex, race/ethnicity, socioeconomic status, baseline BMI *z* score, maternal BMI. Separate analyses by age 2–4 and 4–5 y	No
Sonneville, 2015[12]	50% boys, 50% girls, Project Viva, United States	1163	1	17.1 ± 3.0	8.0 ± 9.6	2 y	Maternal food frequency questionnaire at baseline, then repeated structured interviews with mothers and children (at mean ages 3.1 and 7.7 y)	Change in directly measured BMI *z* score per daily servings (8–15 oz) of 100% fruit juice	Age, sex, weight-for-length *z* score, race/ethnicity, maternal age, maternal education, prepregnancy BMI, household income, and total energy	Yes
Striegel-Moore, 2006[38,39]	100% girls, National Heart, Lung, and Blood Institute Growth and Health Study, United States	2379	9.5	18.6 ± 3.8	3.9 ± 0.2	10 y	3-d diet records by dietician interview (repeated 8× every 1–2 y)	Change in directly measured BMI over 1 y per 100 g/day (3.5 oz) of 100% fruit juice consumed	Age, race, milk, diet soda, sugar-sweetened beverages, coffee/tea, total energy	Yes

TABLE 3 Nonenergy-Adjusted Results of Included Prospective Cohort Studies of Younger Children (Baseline Age ≤6 Years)

	Change in BMI *z* Score Over Time Period		
Baseline Age	<1-y β (95% CI)	2-y β (95% CI)	7-y β (95% CI)
1 y		Sonneville et al,[12] 0.17 (0.00 to 0.33)	Sonneville et al,[12] 0.22 (0.04 to 0.39)
2–3 y	Faith et al,[20] 0.06 (0.019 to 0.101)	Shefferly et al,[1] 0.282 (0.129 to 0.435)	
4 y	Shefferly et al,[1] 0.020 (0.003 to 0.037)		

β, regression coefficient reported by each included study, which expresses the change in BMI *z* score per 1 6- to 8-oz serving/day increment in 100% fruit juice consumed over a period of ≤1 y, 2 y, or 7 y.

TABLE 4 Energy-Adjusted Results of Included Prospective Cohort Studies of Younger Children (Baseline Age <6 Years)

	Change in BMI *z* Score Over Time Period		
Baseline Age	≤ 1-y β (95% CI)	2-y β (95% CI)	7-y β (95% CI)
1 y		Sonneville et al,[12] 0.17 (0.01 to 0.33)	Sonneville et al,[12] 0.23 (0.05 to 0.40)
2–3 y	Newby et al,[24] 0.06 (–0.032 to 0.152)		
4 y			

β, regression coefficient reported by each included study, which expresses the change in BMI *z* score per 1 6- to 8-oz serving/day increment in 100% fruit juice consumed over a period of ≤1 y, 2 y, or 7 y.

juice consumption and change in BMI *z* score (Tables 3 and 4). The mean baseline 100% fruit juice intake ranged from 8.0 oz per day to 18.0 oz per day (Table 2). Younger baseline age and a longer time period over which change in BMI *z* score was measured were associated with higher changes in BMI *z* score.

Sonneville et al[12] found an increase in the BMI z score of 0.17 (95% CI: 0.00 to 0.33; no energy adjustment) for 1-year-olds who consumed 1 to 2 servings per day of 100% fruit juice (8–15 oz/day) over 2 years. This increase in BMI z score was nonconstant across time, with the majority of the increase occurring when the subjects had mean ages of 1 to 3 years (Table 3). Sonneville et al[12] analyzed these same children over 7 years (from mean ages 1–8 years) and found their BMI z score increased by 0.22 (95% CI: 0.04 to 0.39; no energy adjustment). Energy-adjusted analyses produced similar results.

Shefferly et al[1] performed 2 separate analyses and found that age modified the change in BMI z score by an order of magnitude (Table 3). In their first analysis of children with a baseline age of 2 years (n = 8950), Shefferly et al[1] found an increase in BMI z score of 0.28 over 2 years (95% CI: 0.13 to 0.44; no energy adjustment). In their second analysis, considering only the 1-year period between ages 4 and 5 (n = 6250), the BMI z score increased by only 0.02 (95% CI: 0.003 to 0.037; no energy adjustment).

Faith et al[20] followed children with a mean baseline age of 2.5 years and reported the change in BMI z score per month observed over a study period of 6 to 48 months. After application of a scaling factor, per each 1 serving per day increase in 100% fruit juice, Faith et al[20] found an increase in BMI z score of 0.06 over 1 year (95% CI: 0.019 to 0.101; no energy adjustment).

In children with a mean baseline age of 2.9 years, Newby et al[24] found a BMI z score increase of 0.060 per each 6-oz serving per day increase in 100% fruit juice over 6 to 12 months (95% CI: –0.003 to 0.152; serving size scaling factor applied; change in BMI converted to change in BMI z score via the LMS method; energy adjusted).

Three nonenergy-adjusted and 2 energy-adjusted studies in younger children were each pooled (Figs 2 and 3). The pooled regression coefficients should be interpreted as the change in BMI z score per 6- to 8-oz serving per day increment of 100% fruit juice consumed over ~1 year. In nonenergy-adjusted studies, there was significant heterogeneity (I^2 = 67%, P = .049), and the pooled regression coefficient was 0.046 (95% CI: 0.000 to 0.093; random-effects model). In the 2 energy-adjusted studies, the pooled regression coefficient was 0.087 (95% CI: 0.008 to 0.167; fixed-effects model), and there was not significant heterogeneity (I^2 = 27%, P = .24). These increases in pooled BMI z scores translate into absolute increases of 2% (nonenergy-adjusted) to 4% (energy-adjusted) in the BMI percentile over 1 year.

The nonenergy-adjusted and energy-adjusted subgroups pooled different studies, aside from the study by Sonneville et al,[12] which was pooled in both groups. Sonneville et al[12] had the largest effect size and carried more weight in the energy-adjusted group. The difference in BMI z score between the 2 groups is likely due to the fact that the study by Sonneville et al[12] had a larger estimate than Shefferly et al,[1] which dominated the pooled BMI z score change in the nonenergy-adjusted group.

Meta-analysis: Older Children (Baseline Ages 7–18 Years)

None of the 4 studies (combined n = 16498) of older children found statistically significant associations between 100% fruit juice consumption and change in BMI z score (Figs 2 and 3). The mean baseline 100% fruit juice intake ranged from 3.9 oz/d to 6.8 oz/d (Table 2).

Without adjustment for total energy intake, each 6- to 8-oz serving per day increase in 100% fruit juice consumption was associated with a change in BMI z score of 0.000 (95% CI: –0.001 to 0.001; fixed-effects model) over 1 year. After adjustment for total energy intake, the pooled change in BMI z score was 0.003 (95% CI: 0.001 to 0.004; fixed-effects model). Although adjusting for total energy intake made the results statistically significant, an increase in BMI z score of 0.003 translates into a trivial 0% increase in BMI percentile. There was no heterogeneity (I^2 = 0%) in the pooled estimates in older children regardless of energy adjustment.

Removing the study by Dong et al,[34] which reported the longest time period over which change in BMI z score was measured in older children (3 years), increased heterogeneity (I^2 = 45%; P = .14), but did not change the energy-unadjusted pooled estimate. Similarly, pooling reported regression coefficients without any scaling for serving size (ie, analyzing regression coefficients exactly as reported in the original studies) increased heterogeneity, but did not change energy-adjusted or nonenergy-adjusted pooled estimates.

Meta-analysis: All Ages

For children of all baseline ages, the pooled nonenergy-adjusted regression coefficient was 0.002 (95% CI: –0.002 to 0.006; random-effects model), and there was significant heterogeneity (I^2 = 63%; P = .01). The pooled energy-adjusted regression coefficient was 0.003 (95% CI: 0.001 to 0.004; fixed-effects model), and there was not significant heterogeneity (I^2 = 11%; P = .34).

Publication Bias

Visual inspection of the funnel plot (Supplemental Fig 4) suggests a possible lack of published studies with smaller sample sizes that report a nonsignificant effect, because there are no studies with a small SE and a regression coefficient <0.

DISCUSSION

This meta-analysis of prospective cohort studies found a statistically significant association between

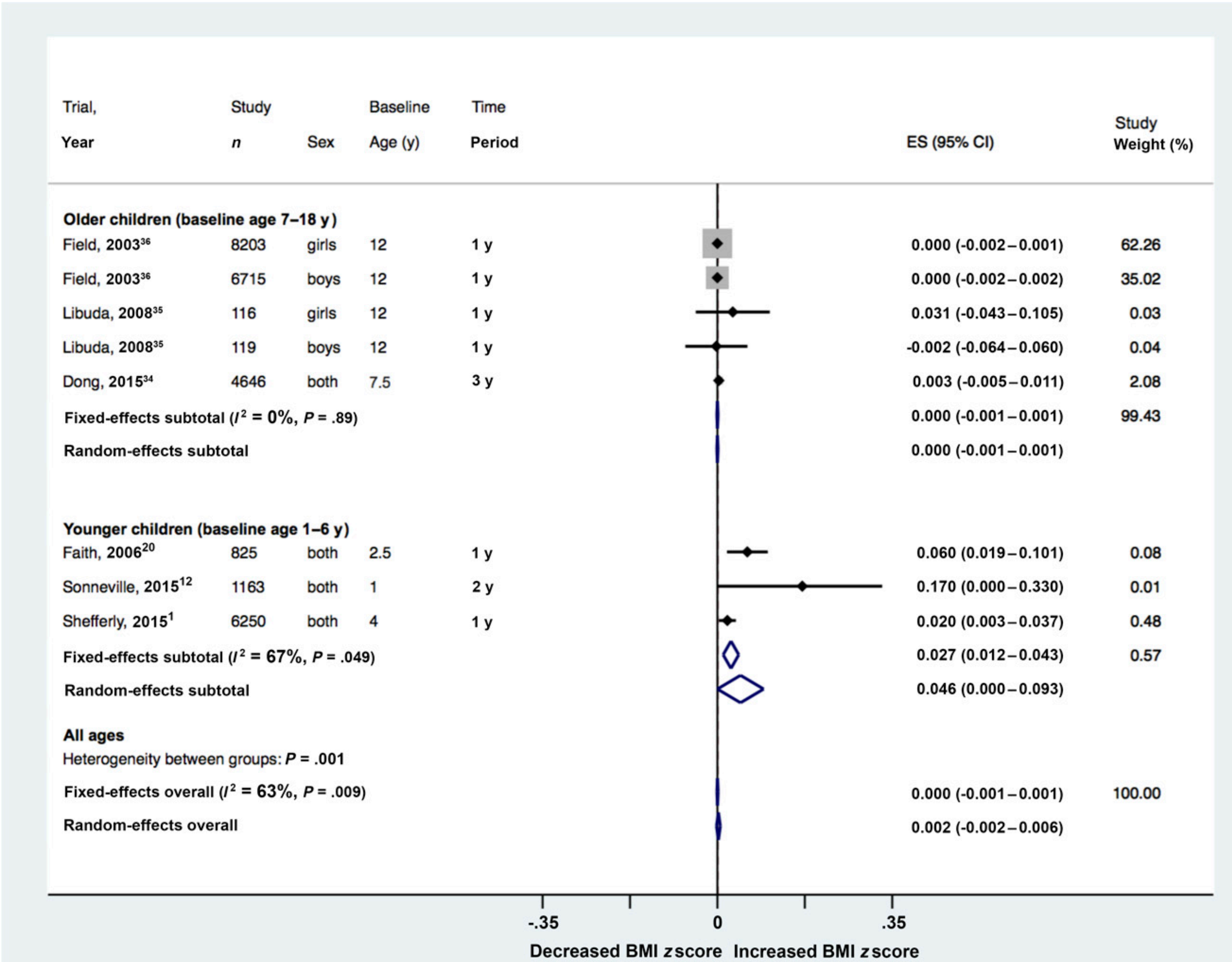

FIGURE 2

Forest plot of change in BMI *z* score per 1 serving/day increment of 100% fruit juice consumed in children (not adjusted for total energy intake). The time period denotes the time over which each study reported the change in BMI *z* score. Although 2 studies reported time periods of BMI *z* score change >1 year, the effect size (ES) may be interpreted as the change in BMI *z* score per 1 serving/day increment of 100% fruit juice consumed over ∼1 year. Horizontal lines denote 95% CIs; solid diamonds represent the point estimate of each study. Gray boxes behind the solid diamonds represent the fixed-effects study weight. Open diamonds represent pooled estimates. The I^2 and *P* values for heterogeneity are shown. Only 6250 of 8950 children in the study by Shefferly et al[1] were included in the meta-analysis (see the Results section).

consumption of 100% fruit juice and increased BMI *z* score in children ≤6 years of age, although the effect size was not clinically meaningful.[21–23] No association was found among children ≥7 years of age. An increase in BMI *z* score over time indicates that a child's weight has increased out of proportion to his or her increase in height. As an example, consider a 5-year-old girl at the 50th percentile for weight (18.0 kg) and BMI (15.2 kg/m^2). An increase of 0.046 to 0.087 BMI *z*–score U over 1 year translates into an increase in this child's BMI percentile to the 52nd to 54th percentile: a weight gain of 0.08 kg to 0.15 kg over 1 year. A small amount of weight gain that is not clinically significant at the individual level may gain significance when considered at the population level.[40] However, to determine whether the association between 100% fruit juice consumption and weight gain in younger children is significant at the population level, additional analyses would need to quantify how changes in the existing levels of 100% fruit juice consumption would translate into changes in the prevalence of overweight/obesity.

Although the pooled estimate of weight gain in younger children (ages 2–6 years) was not clinically significant, individual studies showed clinically significant weight gain in children <2 years of age. Two of the 4 studies of children ≤6 years old, by Shefferly et al[1] and Sonneville et al,[12] were rated to be high quality using the Newcastle-Ottawa Scale and found large, clinically significant increases in BMI *z* scores in children with a baseline age of 1 to 2 years (Table 2). Shefferly et al[1] found their subjects had a smaller increase in BMI *z* scores between the ages of 4

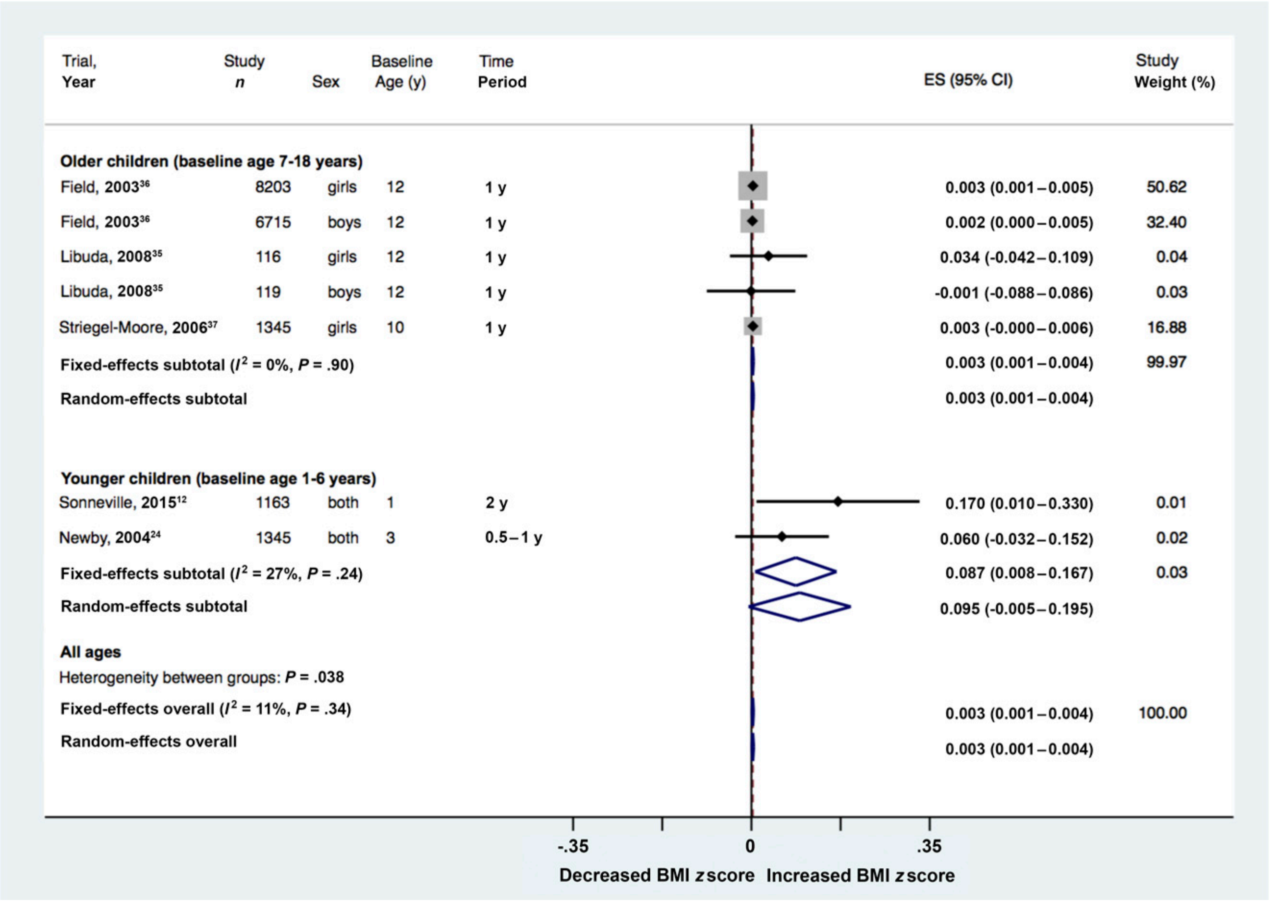

FIGURE 3

Forest plot of change in BMI *z* score per 1 serving/day increment of 100% fruit juice consumed in children (adjusted for total energy intake). Time period denotes the time over which each study reported the change in BMI *z* score. Although 2 studies reported the time period of BMI *z* score change ≠1 year, the effect size (ES) may be interpreted as the change in BMI *z* score per 1 serving/day increment of 100% fruit juice consumed over ~1 year. Horizontal lines denote 95% CIs; solid diamonds represent the point estimate of each study. Gray boxes behind the solid diamonds represent the fixed-effects study weight. Open diamonds represent pooled estimates. The I^2 and *P* values for heterogeneity are shown.

and 5 years, compared with those between the ages of 2 and 4 years. These findings suggest that age may modify the association of 100% fruit juice consumption and change in BMI *z* score in children. It is biologically plausible that children ≤2 years old would be most susceptible to weight gain from consuming 1 serving per day of 100% fruit juice. One 6- to 8-oz serving of 100% fruit juice represents a larger proportion of total daily energy intake in children ≤2 years of age compared with older children.

Associations between 100% fruit juice and weight gain may be stronger among younger versus older children due to differences in the type of 100% fruit juice consumed. Apple juice is the leading type of fruit juice consumed by younger children, whereas orange juice is the leading fruit juice consumed by older children.[41] Studies in adults show that different types of fruit juice may have different effects on cardiometabolic health, which may be due to differing glycemic loads.[42,43] We are not aware of studies in children that compare the health effects of different 100% fruit juice types, but 100% orange juice has a lower glycemic load than 100% apple juice.[44]

Across the studies considered in this meta-analysis, adjustment for total energy intake minimally affected the change in BMI *z* score associated with 100% fruit juice consumption. If we assume that energy intake was measured precisely, these findings suggest a mechanism that is independent of calories. However, self-reported measures of total energy intake are imprecise,[45] precluding our ability to make inferences about the most likely mechanisms.

This study has limitations. All included studies were observational and varied with respect to exposure assessment, outcome assessment, and adjustment for covariates, introducing heterogeneity. Not all studies adjusted for the same covariates, which could impact the magnitude of estimated associations between fruit juice intake and BMI. Measurement error in the exposure assessment may have biased the associations we found. Six of the 8 studies assessed 100% fruit juice exposure at baseline only, as opposed to the change analysis done by Dong et al[34] and Libuda et al[35] that assessed change in 100% fruit juice intake between 2 time points. Analysis of individual dietary components at baseline only, as opposed to change analysis, may cause attenuated associations or reverse causation.[46] Only 1 study, by Dong et al,[34] included participants with baseline ages between 6 years and 9 years, which limits inferences about the association of 100% fruit juice on BMI *z* score in middle childhood. Only 2 studies (energy adjusted)[12,24] or 3 studies (not energy adjusted)[1,12,20] could be pooled for meta-analyses in the younger age group. Finally, 100% fruit juice consumption was not compared with consumption of fruit or another energy source, and this study does not examine the substitution effects of consuming 100% fruit juice in place of whole fruit.

The strengths of this study include an extensive literature search completed by 2 authors at all stages and the inclusion of only longitudinal studies, which represent the highest quality studies published on this topic. We performed analyses both with and without adjustment for total energy intake. We applied more conservative data transformations to the scaling of reported regression coefficients then in previous meta-analyses of sugary beverages and weight gain in children.[19] This systematic review and meta-analysis has a high AMSTAR score (10/11), and there was no beverage industry participation.

CONCLUSIONS

This systematic review and meta-analysis of 8 prospective cohort studies (n = 34 470 individual children) provides evidence that consumption of 1 daily serving increment of 100% fruit juice is associated with a small amount of weight gain in children ≤6 years old, but not in older children. The small amount of weight gain observed in children <6 years old is not clinically significant at the individual level and is of uncertain significance at the population level. Children ages 1 to 2 years may be more susceptible to weight gain from drinking 1 daily serving increment of 100% fruit juice. Randomized controlled trials examining the effect of 100% fruit juice consumption on metabolic and health outcomes, including weight gain and overweight/obesity, are needed in children ages 1 to 6 years. Future studies should standardize 100% fruit juice exposures (serving size), outcomes (eg, change in BMI or BMI *z* score over 1 year) and perform subgroup analyses by 100% fruit juice type. Until additional studies are performed, the AAP's current recommendation that children ages 1 to 6 years limit 100% fruit juice consumption to 4 to 6 oz per day and children ages 7 to 18 limit 100% fruit juice to 8 to 12 oz per day is prudent and should be followed.

ABBREVIATIONS

AAP: American Academy of Pediatrics
AMSTAR: Assessing the Methodological Quality of Systematic Reviews
CENTRAL: Cochrane Central Register of Controlled Trials
CI: confidence interval
DGA: Dietary Guidelines for Americans
LMS: Box-Cox transformation (L), Median (M), Generalized Coefficient of Variation (S)

conceptualized and designed the study, supervised the overall project, and revised the article critically for important intellectual content; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

This systemic review has been registered with the PROSPERO international register of systematic reviews (www.crd.york.ac.uk/PROSPERO) (identifier CRD42016032868).

DOI: 10.1542/peds.2016-2454

Accepted for publication Jan 13, 2017

Address correspondence to Brandon Auerbach, MD, MPH, Division of General Internal Medicine, University of Washington, Harborview Medical Center, Box 359780, 325 Ninth Ave, Seattle, WA 91804. E-mail: auerbach@post.harvard.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: Dr Auerbach is funded by the Ruth L. Kirschstein National Research Service of the National Institutes of Health through the University of Washington (grant T32HP10002). The funding sources had no role in the design, conduct, or analysis of the study, or the decision to submit the manuscript for publication. Funded by the National Institutes of Health (NIH).

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

COMPANION PAPER: A companion to this article can be found online at www.pediatrics.org/cgi/doi/10.1542/peds.2017-0041.

REFERENCES

1. Shefferly A, Scharf RJ, DeBoer MD. Longitudinal evaluation of 100% fruit juice consumption on BMI status in 2–5-year-old children. *Pediatr Obes*. 2016;11(3):221–227
2. Wojcicki JM, Heyman MB. Reducing childhood obesity by eliminating 100% fruit juice. *Am J Public Health*. 2012;102(9):1630–1633
3. Committee on Nutrition, American Academy of Pediatrics. The use and misuse of fruit juice in pediatrics. *Pediatrics*. 2001;107(5):1210–1213
4. Walker RW, Dumke KA, Goran MI. Fructose content in popular beverages made with and without high-fructose corn syrup. *Nutrition*. 2014;30(7-8):928–935
5. US Department of Health and Human Services; US Department of Agriculture (USDA). 2015–2020 Dietary Guidelines for Americans. 8th ed. Available at: http://health.gov/dietaryguidelines/2015/guidelines/. Accessed December 22, 2016
6. US Department of Agriculture, Agricultural Research Service. What we eat in America. NHANES 2011–2012. Table 1a. Fruit: mean daily food patterns cup equivalents consumed per individual, by gender and age, in the United States, 2011–2012. Available at: www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/FPED/tables_1-4_FPED_1112.pdf. Accessed March 24, 2016
7. Nicklas TA, O'Neil CE, Fulgoni VL III. Consumption of 100% fruit juice is associated with better nutrient intake and diet quality but not with weight status in children. *Int J Child Health Nutr*. 2015;(4):112–121
8. Clemens R, Drewnowski A, Ferruzzi MG, Toner CD, Welland D. Squeezing fact from fiction about 100% fruit juice. *Adv Nutr*. 2015;6(2):236S–243S
9. O'Neil CE, Nicklas TA. A review of the relationship between 100% fruit juice consumption and weight in children and adolescents. *Am J Lifestyle Med*. 2008;2(4):315–354
10. Crowe-White K, O'Neil CE, Parrott JS, et al. Impact of 100% fruit juice consumption on diet and weight status of children: an evidence-based review. *Crit Rev Food Sci Nutr*. 2016;56(5):871–884
11. Shea BJ, Grimshaw JM, Wells GA, et al. Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. *BMC Med Res Methodol*. 2007;7:10
12. Sonneville KR, Long MW, Rifas-Shiman SL, Kleinman K, Gillman MW, Taveras EM. Juice and water intake in infancy and later beverage intake and adiposity: could juice be a gateway drink? *Obesity (Silver Spring)*. 2015;23(1):170–176
13. Willett WC. *Nutritional Epidemiology*. 3rd ed. Oxford, United Kingdom: Oxford University Press; 2013
14. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097
15. Booth A, Clarke M, Ghersi D, Moher D, Petticrew M, Stewart L. An international registry of systematic-review protocols. *Lancet*. 2011;377(9760):108–109
16. Babineau J. Product review: Covidence (systematic review software). *J Can Health Libr Assoc*. 2014;35(2):68–71
17. Hebden L, O'Leary F, Rangan A, Singgih Lie E, Hirani V, Allman-Farinelli M. Fruit consumption and adiposity status in adults: a systematic review of current evidence [published online ahead of print June 26, 2015]. *Crit Rev Food Sci Nutr*. doi:10.1080/10408398.2015.1012290
18. Higgins JP, Green S. *Cochrane Handbook for Systematic Reviews of Interventions, Version 5.1.0*. Oxford, United Kingdom: The Cochrane Collaboration; 2011
19. Malik VS, Pan A, Willett WC, Hu FB. Sugar-sweetened beverages and weight gain in children and adults: a systematic review and meta-analysis. *Am J Clin Nutr*. 2013;98(4):1084–1102
20. Faith MS, Dennison BA, Edmunds LS, Stratton HH. Fruit juice intake predicts increased adiposity gain in children from low-income families: weight status-by-environment interaction. *Pediatrics*. 2006;118(5):2066–2075
21. Reinehr T, Lass N, Toschke C, Rothermel J, Lanzinger S, Holl RW. Which amount of BMI-SDS reduction is necessary to improve cardiovascular risk factors in overweight children? *J Clin Endocrinol Metab*. 2016;101(8):3171–3179
22. Trinh A, Campbell M, Ukoumunne OC, Gerner B, Wake M. Physical activity and 3-year BMI change in overweight and obese children. *Pediatrics*. 2013;131(2). Available at: www.pediatrics.org/cgi/content/full/131/2/e470
23. Weiss R, Shaw M, Savoye M, Caprio S. Obesity dynamics and cardiovascular risk factor stability in obese adolescents. *Pediatr Diabetes*. 2009;10(6):360–367
24. Newby PK, Peterson KE, Berkey CS, Leppert J, Willett WC, Colditz GA. Beverage consumption is not associated with changes in weight and body mass index among low-income preschool children in North Dakota. *J Am Diet Assoc*. 2004;104(7):1086–1094
25. Flegal KM, Cole TJ. *Construction of LMS Parameters for the Centers for Disease Control and Prevention 2000 Growth Charts*. Washington, DC: US Department of Health and Human Services; 2013
26. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557–560
27. Borenstein M, Hedges L, Higgins J, Rothstein H. *Introduction to Meta-Analysis*. Chichester, United Kingdom: Wiley; 2009
28. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials*. 1986;7(3):177–188
29. Stata Statistical Software. Release 14. College Station, TX: Stata Corp; 2015
30. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale for assessing the quality of nonrandomized studies in meta-analysis. Available at: www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed March 24, 2016
31. Sichieri R, Yokoo EM, Pereira RA, Veiga GV. Water and sugar-sweetened

beverage consumption and changes in BMI among Brazilian fourth graders after 1-year follow-up. *Public Health Nutr*. 2013;16(1):73–77

32. Wright E, Evans C. Are soft drinks, milk and fruit juice to blame for the childhood obesity epidemic? *Eur J Epidemiol*. 2012;27(1):S134

33. Berkey CS, Rockett HR, Field AE, Gillman MW, Colditz GA. Sugar-added beverages and adolescent weight change. *Obes Res*. 2004;12(5):778–788

34. Dong D, Bilger M, van Dam RM, Finkelstein EA. Consumption of specific foods and beverages and excess weight gain among children and adolescents. *Health Aff (Millwood)*. 2015;34(11):1940–1948

35. Libuda L, Alexy U, Sichert-Hellert W, et al. Pattern of beverage consumption and long-term association with body-weight status in German adolescents--results from the DONALD study. *Br J Nutr*. 2008;99(6):1370–1379

36. Field AE, Gillman MW, Rosner B, Rockett HR, Colditz GA. Association between fruit and vegetable intake and change in body mass index among a large sample of children and adolescents in the United States. *Int J Obes Relat Metab Disord*. 2003;27(7):821–826

37. Najarian M, Snow K, Lennon J, Kinsey S. *Early Childhood Longitudinal Study, Birth Cohort (ECLS-B), Preschool–Kindergarten 2007 Psychometric Report (NCES 2010-009)*. Washington, DC: National Center for Education Statistics, Institute of Education Sciences, US Department of Education; 2010

38. Striegel-Moore RH, Thompson D, Affenito SG, et al. Correlates of beverage intake in adolescent girls: the National Heart, Lung, and Blood Institute Growth and Health Study. *J Pediatr*. 2006;148(2):183–187

39. Obesity and cardiovascular disease risk factors in black and white girls: the NHLBI Growth and Health Study. *Am J Public Health*. 1992;82(12):1613–1620

40. Rose G. Sick individuals and sick populations. *Int J Epidemiol*. 2001;30(3):427–432; discussion 433–434

41. Herrick KA, Rossen LM, Nielsen SJ, Branum AM, Ogden CL. Fruit consumption by youth in the United States. *Pediatrics*. 2015;136(4):664–671

42. Ravn-Haren G, Dragsted LO, Buch-Andersen T, et al. Intake of whole apples or clear apple juice has contrasting effects on plasma lipids in healthy volunteers. *Eur J Nutr*. 2013;52(8):1875–1889

43. Joshipura KJ, Ascherio A, Manson JE, et al. Fruit and vegetable intake in relation to risk of ischemic stroke. *JAMA*. 1999;282(13):1233–1239

44. Atkinson FS, Foster-Powell K, Brand-Miller JC. International tables of glycemic index and glycemic load values: 2008. *Diabetes Care*. 2008;31(12):2281–2283

45. Todd KS, Hudes M, Calloway DH. Food intake measurement: problems and approaches. *Am J Clin Nutr*. 1983;37(1):139–146

46. Smith JD, Hou T, Hu FB, et al. A comparison of different methods for evaluating diet, physical activity, and long-term weight gain in 3 prospective cohort studies. *J Nutr*. 2015;145(11):2527–2534