Beverage Intake During Pregnancy and Childhood Adiposity

Matthew W. Gillman, MD, SM,[a] Sheryl L. Rifas-Shiman, MPH,[a] Silvia Fernandez-Barres, RD, MSc,[b,c] Ken Kleinman, ScD,[d] Elsie M. Taveras, MD, MPH,[e] Emily Oken, MD, MPH[a]

abstract

OBJECTIVES: To examine associations of sugar sweetened beverages (SSBs) and other beverage intake during pregnancy with adiposity in midchildhood (median age of 7.7 years).

METHODS: We studied 1078 mother-child pairs in Project Viva, a prospective prebirth cohort study. Exposures were sugary and nonsugary beverage intake assessed in the first and second trimesters of pregnancy by using a food frequency questionnaire. Main outcome measures were offspring overall adiposity (BMI *z* score, fat mass index [FMI, kg/m^2] from dual-energy radiograph absorptiometry, and sum of subscapular [SS] and triceps [TR] skinfold thicknesses) and central adiposity (SS:TR ratio and waist circumference).

RESULTS: In the second trimester, mean (SD) SSB intake was 0.6 (0.9) servings per day. Thirty-two percent of mothers were multiracial or people of color, 68% were college graduates, and 10% smoked during pregnancy. In midchildhood, mean (SD) BMI *z* score was 0.38 (1.00), and the FMI was 4.4 (1.9) kg/m^2. In multivariable models adjusted for multiple maternal and child covariates, each additional serving per day of SSB was associated with higher BMI *z* scores (0.07 U; 95% confidence interval [CI]: −0.01 to 0.15), FMI (0.15 kg/m^2; 95% CI: −0.01 to 0.30), SS + TR (0.85 mm; 95% CI: 0.06 to 1.64), and waist circumference (0.65 cm; 95% CI: 0.01 to 1.28). Stratified models suggested that the associations were due primarily to maternal, not child, SSB intake and to sugary soda rather than fruit drinks or juice. We did not find differences between boys and girls, nor did we observe the effects of sugar-free soda or of first-trimester beverage intake.

CONCLUSIONS: Higher SSB intake during the second trimester of pregnancy was associated with greater adiposity in midchildhood.

[a]*Division of Chronic Disease Research Across the Lifecourse, Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, Boston, Massachusetts;* [b]*Nutrition and Mental Health Research Group, Universitat Rovira I Virgili, Reus, Spain;* [c]*ISGlobal, Center for Research in Environmental Epidemiology, Barcelona, Spain;* [d]*Department of Biostatistics and Epidemiology, School of Public Health and Health Sciences, University of Massachusetts, Amherst, Massachusetts; and* [e]*Division of General Academic Pediatrics, Department of Pediatrics, Massachusetts General Hospital for Children, Boston, Massachusetts*

Dr Gillman made substantial contributions to the conception and design of the study and the interpretation of the results, obtained funding, and drafted the manuscript; Ms Rifas-Shiman performed the statistical analysis and helped draft and critically revise the manuscript; Dr Kleinman made substantial contributions to the analysis and the interpretation of results and critically revised the manuscript; Ms Fernandez-Barres assisted with the conception and design of the study and critically reviewed the manuscript; Drs Taveras and Oken assisted with the conception and design of the study, helped with the interpretation of the results, and critically reviewed the manuscript; and all authors approved the final version of the manuscript.

Dr Gillman's current affiliation is Environmental Influences on Child Health Outcomes Program, Office of the Director, National Institutes of Health, Bethesda, MD.

WHAT'S KNOWN ON THIS SUBJECT: Maternal diet during pregnancy may entrain offspring obesity. One potential dietary factor is sugar-sweetened beverages, intake of which appears to cause obesity in children and adults.

WHAT THIS STUDY ADDS: In this prospective prebirth cohort study, school-aged children of mothers who consumed more sugary beverages in midpregnancy had higher levels of adiposity, measured by BMI, skinfold thicknesses, and dual-energy radiograph absorptiometry.

To cite: Gillman MW, Rifas-Shiman SL, Fernandez-Barres S, et al. Beverage Intake During Pregnancy and Childhood Adiposity. *Pediatrics.* 2017;140(2):e20170031

One set of solutions for the worldwide childhood obesity pandemic emphasizes prevention in the early, plastic stages of human development, when the right cues could set lifelong trajectories of optimal health.[1] Decades of animal experiments show that perturbations during early, sensitive periods of development affect fat deposition and development of cardiometabolic dysfunction.[2] Many of these experiments comprise alterations in the diet of pregnant mothers, including reductions in energy or protein intake or, more recently, high fat diets, westernized diets, and high-sugar diets.[3–5] Although these experiments provide proof of principle, the experimental energy and protein restriction tend to be out of the physiologic range of humans, many of the components of "overnutrition" diets in animal models do not have analogs in the human diet, and the variation in experimental paradigms make translation to the human condition indirect at best.[6]

In humans, it has been more challenging to demonstrate robust associations between the diets of pregnant women and obesity in their offspring. One reason is a focus on nutrients, akin to the animal studies, rather than foods. Although nutrient-based studies[7–10] may more closely approach causal mechanisms, foods are what people buy, cook, and eat, and thus food-based recommendations are easier to "absorb."[7–10] In addition, dietary assessment begins with asking about foods; nutrient calculations rely on external databases as well as reported food intake, thus introducing multiple sources of error. Another reason is that few cohort studies with accurate dietary assessment in pregnancy have child follow-up to school age,[11] when obesity becomes a good predictor of later adverse health outcomes,[12] and none, to our knowledge, have examined maternal beverage intake.

Sugar-sweetened beverage (SSB) intake is a prime target of obesity prevention and treatment strategies in nonpregnant adults and children. Numerous observational studies and meta-analyses in adults, and some among children, demonstrate that intake of SSBs predicts excess weight gain, obesity, metabolic syndrome, and type 2 diabetes.[13–15] National and local policies are geared toward reducing consumption of sugary beverages, and in recent years in the United States (but not abroad), sugary soda consumption has begun to decline.[15–18] Despite the clarity from observational studies, 2 recent intervention studies to reduce SSBs among children and adolescents, especially 1 among already overweight or obese adolescents, revealed only modest effects on weight-related outcomes, perhaps because physiologic plasticity is already waning at those ages.[19–21] Once obesity takes hold, physiologic, behavioral, and social forces tenaciously fight against weight control, even in childhood.[22,23]

The purpose of this study was to investigate associations of sugary and nonsugary beverage consumption during pregnancy with obesity-related outcomes in midchildhood among mother-child pairs participating in the prebirth cohort study Project Viva.

METHODS

Between 1999 and 2002, we recruited women into Project Viva in early pregnancy from 8 obstetric offices of Atrius Harvard Vanguard Medical Associates, a multispecialty group practice in eastern Massachusetts.[24] Details of recruitment and retention are published.[24] Of the 2128 women who delivered a live singleton infant, we excluded from this analysis 59 participants with previous type 1 or type 2 diabetes mellitus or gestational diabetes in a previous pregnancy, 44 participants who were born before 34 weeks' gestational age, and 947 participants who did not attend the midchildhood in-person visit. Thus, our sample size for analysis was 1078 mother-child pairs. Compared with the 1078 participants in this analysis, the 947 nonparticipants were somewhat less likely to have college-educated mothers (62% vs 68%) and to have annual household income exceeding $70 000 (56% vs 61%), and the mean maternal age was slightly lower (31.5 vs 32.1 years). Maternal race and/or ethnicity (33% vs 32% multiracial or people of color) and BMI (mean of 24.8 vs 24.6) and intake of second-trimester SSBs (mean of 0.69 vs 0.63 servings per day), however, were similar.

After obtaining written informed consent, we performed in-person study visits with participating mothers at the end of the first and second trimesters of pregnancy and with mothers and children during the first few days after delivery and in infancy (median age of 6.3 months), early childhood (median age of 3.2 years), and midchildhood (median age of 7.7 years). Mothers completed mailed questionnaires at 1, 2, 4, 5, and 6 years of age. The institutional review boards of Harvard Pilgrim Health Care, Brigham and Women's Hospital, and Beth Israel Deaconess Medical Center approved the study protocols.

Exposures

We obtained data on consumption of beverages during pregnancy from semiquantitative food frequency questionnaires (FFQs) that expectant mothers completed after the first and second research visits, at the mean (SD) gestational ages of 11.9 (3.5) and 29.2 (2.6) weeks. Each of the 2 FFQs was slightly modified for use in pregnancy from a commonly used adult FFQ from which SSB intake

predicts a number of cardiometabolic outcomes.[13–15,25,26] Participants endorsed categories of frequency of beverage consumption from "never/less than 1 per month" to a maximum of "2 or more glasses per day" for some fruit juices, "4 or more cans per day" for soda, and "6 or more glasses per day" for water. The time referent for the first-trimester FFQ was "during this pregnancy," that is, from the woman's last menstrual period until she completed the FFQ. For the second-trimester FFQ, the time referent was the previous 3 months. The FFQ included 3 questions on regular (sugary) soda intake, 3 questions on sugar-free soda, 5 questions on fruit juice, 1 question on fruit drinks, and 2 questions on water. We defined SSBs as regular soda and fruit drinks. We also included fruit juice, sugar-free soda (diet soda), and water in our analyses. Although the FFQ included 4 questions regarding the type of milk consumed, it did not include specific information about sweetened and flavored milk. Therefore, we did not include dairy products in this analysis, nor did we include tea or coffee, although these were queried on the FFQs.

Outcome Measures

At the midchildhood visit (median age of 7.7 years, range of 6.6–10.9 years), trained research staff measured each child's height to the nearest 0.1 cm and weight to the nearest 0.1 kg with a calibrated stadiometer (Shorr Productions, Olney, MD) and calibrated scale (Tanita model TBF-300A; Tanita Corporation of America, Inc, Arlington Heights, IL). We calculated age- and sex-specific BMI *z* scores by using US national reference data.[27] We also measured total fat mass with dual-energy radiograph absorptiometry (DXA) (Discovery A model; Hologic Inc, Marlborough, MA), and we calculated fat mass index (FMI) as fat mass in kilograms divided by height in meters squared, analogous to BMI. We measured waist circumference to the nearest 0.1 cm with a Hoechstmass measuring tape (Hoechstmass Balzer GmbH, Sulzbach, Germany), and subscapular skinfold thickness (SS) and triceps skinfold thickness (TR) to the nearest 0.1 mm with Holtain calipers (Holtain LTD, Crosswell, UK) and calculated their sum (SS + TR) and ratio (SS:TR). Research assistants performing all measurements followed standardized techniques[28] and participated in in-service training to ensure measurement validity (IJ Shorr; Shorr Productions). Inter- and intrarater measurement errors were within published reference ranges for all measurements.[29]

Covariates

At each in-person and mailed visit from early pregnancy through the midchildhood outcome visit, as well as from outpatient and hospital medical records, we collected information on many potentially confounding, mediating, and moderating variables. We collected sociodemographic and medical data at enrollment, with regular updates. Mothers reported their age, race and/or ethnicity, education, parity, prepregnancy weight and height, and paternal weight and height. We calculated total gestational weight gain by subtracting self-reported prepregnancy weight from the last prenatal weight from medical records. We calculated gestational age by using the date of the last menstrual period, but if the early second-trimester ultrasound assessment differed from the calculated gestational age by more than 10 days, we used the ultrasound dating instead. We obtained birth weight from medical records. At appropriate ages, mothers reported the number of hours their children spent in child care, timing of solid food introduction, breastfeeding duration, child diet, television viewing, and physical activity habits.[30–32]

To explore mediation or moderation by child's beverage intake, we used data from a beverage frequency questionnaire that mothers completed at the midchildhood visit. This questionnaire, with 7 response categories from "never" to "5 or more times per day" for each beverage, included 11 questions on milk intake, including flavored milk (which typically contains added sugars); 1 question each on regular and sugar-free soda; 2 questions on fruit juice; 1 question on fruit drinks; and 1 question on water. To facilitate consistency with the maternal prenatal report of beverage intake, in our primary analysis we did not include sweetened flavored milk in our calculations of child intake of SSBs. In a secondary analysis, inclusion of sweetened flavored milks did not materially change the findings.

Data Analysis

The main elements of our analytic approach included multivariable linear and logistic regression to account for confounding and to explore mediation, stratification to examine effect modification, and multiple imputation to compensate for missing data. Our primary exposure was beverage consumption in the second trimester of pregnancy, expressed as a continuous variable in regression models, but displayed as <0.5, 0.5 to <1, 1 to <2, 2 to <3, or at least 3 servings per day in tables. We also examined first-trimester intake and, additionally, the change from first to second trimester because preliminary data showed that changes in SSB consumption predicted gestational weight gain during the same period.[33] Gestational weight gain itself is a predictor of offspring obesity in this and other populations.[34] Main midchildhood outcomes included BMI *z* score, obesity, FMI, sum of SS + TR skinfolds

for overall adiposity, and the ratio of SS:TR and waist circumference for central adiposity.

To examine exposure-outcome relationships, we initially examined exposures as categorical variables (quartiles). Because trends across quartiles were linear, we expressed exposures as continuous variables in regression models. We built multivariable linear regression models in which we adjusted for maternal age, race and/or ethnicity, education, smoking, parity, and prepregnancy BMI; household income; and child sex and exact age at the time of the midchildhood visit. Adding other potentially confounding variables, including maternal intake of fried food away from home, carbohydrates, fatty acids, total energy intake, fetal growth, breastfeeding duration, midchildhood sleep duration, television viewing, and physical activity, did not materially change the observed associations, so we did not include them in our final models. We did not adjust for gestational weight gain and fetal growth because they might be on the causal pathway and would be likely to attenuate the total associations. We also considered whether lack of covariate overlap between exposed (maternal SSB intake ≥2 servings per day) and unexposed (<2 servings per day) drove results. We used propensity scores to define overlapping covariate values, or "common support." We ran common-support regression after excluding 11 participants for whom 1 or the other exposure group provided few data, and results were similar.[35] To examine effect modification, we stratified adjusted models by maternal prepregnancy BMI, child sex, and child race and/or ethnicity in separate models. To examine the mediating or moderating effect of child beverage intake, we dichotomized both maternal and midchildhood sugary beverage intake at cut points defined post hoc by examination of the data and examined effects within each of the 4 resulting strata; as an alternative approach, we added child intake as a covariate.

When including a single beverage as an exposure, these regression approaches essentially reveal the effect of adding servings of a beverage to one's diet. We also explored effects of substituting each type of beverage for SSBs by fitting models that also included total beverage intake and all beverage types except SSBs. This type of model may more accurately reflect the common practice of drinking 1 type of beverage instead of another, rather than adding it to total fluid intake.[36]

To account for missing data, we performed multiple imputation for all 2128 mother-child pairs in Project Viva. We then limited the analysis to the 1078 included participants. We used SAS (Proc MI) to impute 50 values for each missing observation and combined multivariable modeling estimates by using Proc MI ANALYZE in SAS version 9.3 (SAS Institute, Cary, NC). An alternative approach, including only participants with all covariate data (complete cases), yielded similar results. Because we observed approximately linear effects across quartiles of intake, we reported regression estimates and their 95% confidence intervals (CIs) for each increment of 1 serving per day of beverage intake as a continuous variable.

RESULTS

Mean (SD) maternal age at enrollment was 32.1 (5.4) years, prepregnancy BMI was 24.6 (5.2), and total gestational weight gain was 15.6 (5.3) kg; 32% of the participants were multiracial or people of color, 10% smoked during pregnancy, 68% were college graduates, and 39% had household incomes ≤$70 000 per year (Table 1).

In the second trimester, mean (SD, range) sugary beverage intake was 0.6 (0.9, 0.0–8.3) servings per day. Over half consumed <0.5 servings per day, and fewer than 10% drank more than 2 servings per day. Mean intakes of juice, diet soda, and water were 1.4, 0.1, and 4.5 servings per day, respectively (Table 2).

Correlates of higher second-trimester consumption of sugary beverages included younger maternal age, higher prepregnancy BMI, multicracial race and/or ethnicity, lower education and household income, smoking during pregnancy, shorter breastfeeding duration, and earlier introduction of solid foods (Table 1). In midchildhood, mean (SD) BMI *z* score was 0.38 (1.00) and 272/1078 (25.2%) of the children were overweight or obese, that is, BMI exceeding the age-sex–specific 85th percentile. These and the other adiposity outcomes were highest among children whose mothers consumed at least 2 servings per day of sugary beverages (Table 1). The Spearman correlation coefficient was 0.27 between maternal second-trimester and child midchildhood consumption of sugary beverages, 0.07 between maternal second-trimester consumption and child midchildhood BMI *z* score, and 0.10 between child consumption and BMI *z* score.

In multivariable models (Table 3), we found that maternal second-trimester intake of sugary beverages was related to all child overall adiposity and central adiposity outcomes. Unadjusted estimates (95% CIs) for each additional serving per day included 0.15 U (0.07 to 0.23) for BMI *z* score, 0.31 kg/m^2 (0.15 to 0.47) for FMI, 1.76 mm (0.94 to 2.59) for SS + TR, 2.12 (0.65 to 3.60) for SS:TR, and 1.47 cm (0.79 to 2.15) for waist circumference. These estimates were attenuated by adjusting for sociodemographic variables and maternal prepregnancy BMI and

TABLE 1 Characteristics Among 1078 Mother-Child Pairs Participating in Project Viva, Total and According to Category of Intake of SSBs in the Second Trimester of Pregnancy

Characteristic	Category of Maternal Second-Trimester SSB Intake (Servings/d)					
	Total	0 to <0.5	0.5 to <1	1 to <2	2 to <3	≥3
	N = 1078	*n* = 623 (57.8%)	*n* = 241 (22.4%)	*n* = 128 (11.9%)	*n* = 57 (5.2%)	*n* = 29 (2.7%)
				Mean (SD)		
Maternal						
Age at enrollment, y	32.1 (5.4)	33.0 (5.1)	31.3 (5.2)	30.6 (5.6)	30.3 (5.9)	27.7 (5.4)
Prepregnancy BMI	24.6 (5.2)	24.1 (4.7)	24.9 (5.4)	25.6 (5.5)	25.3 (6.1)	27.1 (6.9)
Gestational age at first FFQ, wk	11.9 (3.2)	11.9 (3.3)	11.7 (3.1)	11.9 (3.2)	12.3 (3.4)	11.7 (3.3)
Gestational age at second FFQ, wk	29.2 (2.5)	29.2 (2.4)	29.2 (2.6)	29.4 (2.5)	29.3 (2.8)	29.6 (2.4)
Total gestational weight gain, kg	15.6 (5.3)	15.8 (4.9)	15.4 (5.2)	15.2 (6.4)	15.8 (5.9)	12.9 (6.9)
				N (%)		
Race and/or ethnicity						
African American	176 (16.4)	83 (13.3)	40 (16.8)	28 (21.7)	15 (27.2)	10 (33.9)
Hispanic	70 (6.5)	31 (4.9)	21 (8.5)	13 (10.0)	4 (6.5)	2 (6.5)
Asian American	53 (5.0)	40 (6.4)	8 (3.4)	3 (2.5)	2 (3.5)	0 (0.0)
White	730 (67.7)	446 (71.5)	164 (67.8)	77 (60.0)	30 (53.1)	14 (47.6)
Other	49 (4.5)	24 (3.8)	8 (3.4)	7 (5.8)	5 (9.6)	4 (12.1)
College graduate						
No	347 (32.2)	163 (26.2)	82 (33.9)	55 (43.2)	24 (42.8)	22 (76.0)
Yes	731 (67.8)	460 (73.8)	160 (66.1)	73 (56.8)	32 (57.2)	7 (24.0)
Household income >$70 000						
No	424 (39.3)	222 (35.6)	94 (39.1)	59 (46.5)	28 (48.9)	21 (72.4)
Yes	654 (60.7)	402 (64.4)	147 (60.9)	68 (53.5)	29 (51.1)	8 (27.6)
Smoking status						
Never	766 (71.0)	456 (73.1)	165 (68.5)	85 (66.8)	39 (69.0)	20 (70.0)
Former	206 (19.1)	120 (19.3)	49 (20.3)	27 (21.1)	9 (15.2)	1 (4.5)
Smoked during pregnancy	106 (9.8)	47 (7.6)	27 (11.2)	15 (12.1)	9 (15.8)	7 (25.6)
Nulliparous						
No	562 (52.1)	338 (54.3)	112 (46.2)	65 (51.0)	30 (53.3)	17 (57.8)
Yes	516 (47.9)	285 (45.7)	130 (53.8)	63 (49.0)	26 (46.7)	12 (42.2)
Prepregnancy BMI category						
<25	702 (65.2)	431 (69.2)	152 (63.1)	70 (55.0)	36 (63.5)	13 (43.0)
≥25	376 (34.8)	192 (30.8)	89 (36.9)	58 (45.0)	21 (36.5)	17 (57.0)
				N (%)		
Child						
Boy	535 (49.6)	312 (50.1)	120 (49.5)	61 (47.7)	30 (52.7)	12 (42.9)
Girl	543 (50.4)	311 (49.9)	122 (50.5)	67 (52.3)	27 (47.3)	17 (57.1)
				Mean (SD)		
Gestational age at birth, wk	39.7 (1.4)	39.7 (1.3)	39.7 (1.5)	39.5 (1.5)	39.8 (1.5)	39.3 (1.5)
Fetal growth *z* score	0.19 (0.97)	0.19 (0.96)	0.25 (0.97)	0.19 (0.95)	−0.01 (1.09)	−0.12 (1.03)
Breastfeeding duration, mo	6.5 (4.6)	7.0 (4.5)	6.4 (4.5)	4.7 (4.4)	5.0 (4.5)	4.5 (4.4)
Midchildhood						
Age, y	8.0 (0.9)	7.9 (0.8)	8.0 (0.8)	8.0 (0.8)	8.1 (1.0)	8.3 (1.0)
Height, cm	128.8 (7.7)	128.3 (7.6)	129.2 (7.7)	129.1 (7.9)	129.7 (7.6)	132.9 (8.8)
Weight, kg	28.9 (7.8)	28.2 (7.1)	29.1 (7.6)	29.4 (8.2)	30.6 (9.0)	35.7 (12.9)
BMI	17.2 (3.1)	17.0 (2.9)	17.2 (2.9)	17.4 (3.2)	18.0 (3.7)	19.7 (4.7)
BMI *z* score	0.38 (1.00)	0.32 (0.96)	0.39 (1.00)	0.41 (1.12)	0.56 (1.05)	1.03 (0.95)
DXA FMI, kg/m^2	4.4 (1.9)	4.3 (1.7)	4.4 (1.9)	4.5 (1.9)	4.8 (2.5)	5.7 (2.9)
Sum of SS + TR, mm	19.8 (9.7)	19.0 (8.9)	19.9 (10.0)	20.6 (10.2)	22.5 (12.3)	26.0 (13.1)
Ratio of SS:TR	70.3 (18.7)	69.1 (17.4)	71.3 (19.7)	70.0 (19.0)	73.8 (20.9)	82.2 (23.9)
Waist circumference, cm	59.9 (8.2)	59.2 (7.5)	60.4 (8.3)	60.5 (8.4)	61.7 (10.5)	65.6 (12.8)
				N (%)		
BMI category						
<85th percentile	806 (74.8)	484 (77.7)	174 (72.0)	93 (72.9)	39 (69.2)	16 (54.9)
85th to <95th percentile	142 (13.1)	76 (12.1)	38 (15.9)	15 (11.6)	8 (13.4)	5 (17.6)
≥95th percentile	130 (12.1)	63 (10.1)	29 (12.2)	20 (15.5)	10 (17.4)	8 (27.5)

smoking. For example, the adjusted estimate (95% CI) for BMI *z* score was 0.07 U (−0.01 to 0.15) and for FMI was 0.15 kg/m^2 (−0.01 to 0.30). In logistic regression, the adjusted odds ratio (OR) for childhood BMI exceeding the 85th percentile was 1.14 (0.95 to 1.36). Only maternal consumption of SSBs (0.07 U; −0.01 to 0.15), not juice, diet soda, or water, was associated with BMI *z* score (Table 4). Between the 2

TABLE 2 Beverage Intake Among 1078 Mother-Child Pairs Participating in Project Viva, Total and According to Category of Intake of SSBs in the Second Trimester of Pregnancy

	Category of Maternal Second-Trimester SSB Intake (Servings/d)					
	Total	0 to <0.5	0.5 to <1	1 to <2	2 to <3	≥3
	N = 1078	*n* = 623 (57.8%)	*n* = 241 (22.4%)	*n* = 128 (11.9%)	*n* = 57 (5.2%)	*n* = 29 (2.7%)
Maternal first-trimester intake, servings/d			Mean (SD)			
SSB	0.6 (0.9)	0.3 (0.5)	0.7 (0.8)	1.1 (1.0)	1.8 (1.2)	2.6 (1.6)
Sugary soda	0.3 (0.6)	0.2 (0.3)	0.4 (0.5)	0.7 (0.8)	0.9 (1.1)	1.3 (1.2)
Fruit drinks	0.3 (0.6)	0.2 (0.3)	0.4 (0.6)	0.4 (0.5)	0.8 (1.0)	1.4 (1.3)
Juice	1.3 (1.0)	1.2 (0.9)	1.5 (1.0)	1.4 (1.1)	1.7 (1.3)	2.1 (1.7)
Diet soda	0.2 (0.5)	0.2 (0.5)	0.2 (0.5)	0.2 (0.4)	0.3 (0.5)	0.3 (0.8)
Water	3.8 (1.9)	4.1 (1.8)	3.8 (1.8)	3.4 (2.0)	3.2 (1.9)	2.6 (2.0)
Maternal second-trimester intake, servings/d						
SSB	0.6 (0.9)	0.1 (0.1)	0.7 (0.2)	1.3 (0.2)	2.5 (0.3)	4.1 (0.9)
Sugary soda	0.3 (0.5)	0.1 (0.1)	0.4 (0.2)	0.7 (0.4)	0.9 (1.0)	1.6 (1.3)
Fruit drinks	0.3 (0.6)	0.1 (0.1)	0.3 (0.2)	0.6 (0.4)	1.6 (1.1)	2.4 (1.3)
Juice	1.4 (1.1)	1.2 (1.0)	1.4 (1.0)	1.7 (1.4)	2.0 (1.5)	2.3 (1.7)
Diet soda	0.1 (0.5)	0.1 (0.4)	0.2 (0.8)	0.1 (0.4)	0.1 (0.3)	0.2 (0.5)
Water	4.5 (2.2)	4.8 (2.2)	4.6 (2.0)	4.0 (2.3)	3.9 (2.2)	3.2 (2.3)
Midchildhood intake, servings/wk						
SSB	2.6 (4.7)	2.1 (4.4)	2.4 (4.0)	3.7 (5.0)	5.0 (7.7)	3.5 (3.6)
Sugary soda	0.5 (1.2)	0.4 (0.9)	0.6 (1.6)	0.8 (1.3)	0.7 (1.1)	1.1 (1.8)
Fruit drinks	2.1 (4.2)	1.7 (4.0)	1.8 (3.0)	2.9 (4.7)	4.3 (7.4)	2.5 (3.0)
Juice	7.7 (8.0)	7.4 (7.9)	7.3 (7.9)	8.3 (8.0)	10.2 (9.3)	9.2 (8.0)
Diet soda	0.3 (1.7)	0.3 (1.4)	0.5 (2.7)	0.3 (0.9)	0.3 (1.2)	0.4 (1.5)
Water	18.1 (10.8)	17.9 (10.7)	18.6 (10.4)	18.2 (11.8)	17.8 (10.2)	19.4 (12.6)

types of sugary beverages, maternal intake of soda demonstrated the stronger association (0.11 U; −0.02 to 0.23) than did fruit drinks (0.06 U; −0.05 to 0.17), although CIs were wide and crossed 0. Estimates for juice 0.01 (−0.05 to 0.06), diet soda 0.07 (−0.05 to 0.18), and water 0.00 (−0.03 to 0.03) were null. DXA FMI results (Table 5) were similar to BMI *z* score results (Table 4).

We did not observe different effects among offspring of overweight or obese (BMI ≥25) versus normal-weight mothers (interaction *P* value = .88), or boys versus girls (interaction *P* value = .25), or children of white versus African American versus other race and/or ethnicity (interaction *P* value = .12) (Table 4). In addition, including child beverage intake in the models did not appreciably attenuate the estimates (Tables 3–5). For example, the associations of maternal SSB intake and BMI *z* score (0.07 U; −0.01 to 0.15) and FMI (0.15 kg/m^2; −0.01 to 0.30) were the same before and after adjusting for child SSB intake. In these models, each additional SSB serving per day in children was not associated with BMI *z* score (−0.04 U; −0.13 to 0.05) or total FMI (0.00 kg/m^2; −0.17 to 0.17). In logistic regression, the adjusted OR for childhood BMI ≥85th percentile was the same before and after adjusting for child SSB intake (OR: 1.14; 0.95 to 1.36). In this model, including both maternal and child intake, each additional SSB serving per day in children was not associated with BMI ≥85th percentile (OR: 1.01; 0.81 to 1.25).

Furthermore, models stratified simultaneously according to maternal and child intake suggested that the associations were primarily driven by maternal intake, although some of the CIs were wide and overlapping (Fig 1). We examined maternal intake of at least versus <2 servings per day and child intake of at least versus <0.5 servings per week and their interaction. Compared with lower intakes in both mother and child, higher intake in children alone was associated with a higher BMI *z* score of 0.08 (95% CI: −0.06 to 0.22) whereas higher maternal intake was associated with BMI *z* score increments of 0.22 (−0.37 to 0.80) and 0.29 (0.01 to 0.56) among children with lower and higher intakes, respectively (Fig 1A).

TABLE 3 Associations of Second-Trimester Intake of SSBs With Adiposity Outcomes in Midchildhood

	Unadjusted	Adjusted[a]	Adjusted[a] and Child SSB Intake
	Difference in Outcome (95% CI) Per 1 Serving/d Increment of Second-Trimester SSB Intake		
Outcome			
BMI *z* score	0.15 (0.07 to 0.23)	0.07 (−0.01 to 0.15)	0.07 (−0.01 to 0.15)
DXA FMI, kg/m^2	0.31 (0.15 to 0.47)	0.15 (−0.01 to 0.30)	0.15 (−0.01 to 0.30)
SS + TR, mm	1.76 (0.94 to 2.59)	0.85 (0.06 to 1.64)	0.85 (0.06 to 1.64)
SS:TR	2.12 (0.65 to 3.60)	1.28 (−0.22 to 2.77)	1.25 (−0.25 to 2.75)
Waist circumference, cm	1.47 (0.79 to 2.15)	0.65 (0.01 to 1.28)	0.64 (0.00 to 1.27)

Data are from 1078 mother-child pairs participating in Project Viva. SS:TR models are additionally adjusted for BMI *z* score.
[a] Adjusted for maternal age, race and/or ethnicity, education, smoking, parity, and prepregnancy BMI; household income; and child age and sex.

TABLE 4 Associations of Second-Trimester Intake of Beverages With BMI *z* Score in Midchildhood, Overall and According to Maternal BMI, Maternal Race and/or Ethnicity, and Child Sex

		Unadjusted	Adjusted[a]	Additionally Adjusted for Child Beverage Intake
	N	Difference in BMI *z* Score (95% CI) Per 1 Serving/d Increment in Maternal Beverage Intake		
SSB	1078	0.15 (0.07 to 0.23)	0.07 (−0.01 to 0.15)	0.07 (−0.01 to 0.15)
Sugary soda	1078	0.23 (0.10 to 0.36)	0.11 (−0.02 to 0.23)	0.12 (−0.01 to 0.25)
Fruit drinks	1078	0.13 (0.02 to 0.24)	0.06 (−0.05 to 0.17)	0.06 (−0.04 to 0.17)
Juice	1078	0.02 (−0.04 to 0.08)	0.01 (−0.05 to 0.06)	0.01 (−0.05 to 0.07)
Diet soda	1078	0.12 (0.00 to 0.24)	0.07 (−0.05 to 0.18)	0.02 (−0.12 to 0.15)
Water	1078	−0.01 (−0.04 to 0.02)	0.00 (−0.03 to 0.03)	0.00 (−0.03 to 0.03)
		Difference in BMI *z* Score (95% CI) Per 1 Serving/d Increment in Second-Trimester SSB Intake		
By maternal prepregnancy BMI				
<25	702	0.10 (0.00 to 0.19)	0.07 (−0.03 to 0.17)	0.08 (−0.02 to 0.18)
≥25	376	0.14 (0.02 to 0.27)	0.08 (−0.04 to 0.20)	0.08 (−0.04 to 0.20)
By maternal race and/or ethnicity				
African American	176	0.17 (0.01 to 0.34)	0.14 (−0.03 to 0.30)	0.14 (−0.03 to 0.30)
White	730	0.04 (−0.05 to 0.13)	0.00 (−0.09 to 0.09)	0.01 (−0.08 to 0.10)
Other (Hispanic, Asian American, other)	172	0.30 (0.08 to 0.51)	0.19 (−0.02 to 0.41)	0.21 (−0.01 to 0.43)
By child sex				
Boy	535	0.10 (−0.01 to 0.21)	0.03 (−0.08 to 0.14)	0.04 (−0.08 to 0.15)
Girl	543	0.19 (0.08 to 0.30)	0.09 (−0.02 to 0.19)	0.09 (−0.01 to 0.19)

Data from 1078 mother-child pairs participating in Project Viva.

[a] Adjusted for maternal age, race and/or ethnicity, education, smoking, parity, and prepregnancy BMI; household income; and child age and sex. Models stratified by race and/or ethnicity do not include race and/or ethnicity as a covariate. Models stratified by sex do not include sex as a covariate.

TABLE 5 Associations of Second-Trimester Intake of Beverages With DXA FMI (kg/m^2) in Midchildhood, Overall and According to Maternal BMI, Maternal Race and/or Ethnicity, and Child Sex

		Unadjusted	Adjusted[a]	Additionally Adjusted for Child Beverage Intake
	N	Difference in DXA FMI (95% CI) Per 1 Serving/d Increment in Maternal Beverage Intake		
SSB	1078	0.31 (0.15 to 0.47)	0.15 (−0.01 to 0.30)	0.15 (−0.01 to 0.30)
Sugary soda	1078	0.46 (0.19 to 0.72)	0.19 (−0.06 to 0.44)	0.21 (−0.05 to 0.47)
Fruit drinks	1078	0.29 (0.06 to 0.52)	0.15 (−0.07 to 0.36)	0.15 (−0.07 to 0.36)
Juice	1078	0.07 (−0.06 to 0.19)	0.04 (−0.07 to 0.15)	0.06 (−0.05 to 0.17)
Diet soda	1078	0.27 (0.02 to 0.52)	0.17 (−0.05 to 0.39)	0.01 (−0.25 to 0.27)
Water	1078	0.01 (−0.05 to 0.07)	0.03 (−0.02 to 0.09)	0.03 (−0.03 to 0.08)
		Difference in DXA FMI (95% CI) Per 1 Serving/d Increment in Second-Trimester SSB Intake		
By maternal prepregnancy BMI				
<25	702	0.25 (0.10 to 0.41)	0.19 (0.03 to 0.34)	0.19 (0.03 to 0.35)
≥25	376	0.27 (−0.03 to 0.57)	0.10 (−0.19 to 0.39)	0.10 (−0.19 to 0.39)
By maternal race and/or ethnicity				
African American	176	0.46 (0.00 to 0.92)	0.30 (−0.13 to 0.73)	0.30 (−0.13 to 0.73)
White	730	0.09 (−0.08 to 0.25)	−0.01 (−0.17 to 0.15)	0.00 (−0.16 to 0.16)
Other (Hispanic, Asian American, other)	172	0.55 (0.17 to 0.93)	0.38 (0.00 to 0.76)	0.37 (−0.02 to 0.76)
By child sex				
Boy	535	0.20 (−0.01 to 0.41)	0.05 (−0.16 to 0.27)	0.06 (−0.16 to 0.27)
Girl	543	0.40 (0.18 to 0.61)	0.18 (−0.02 to 0.39)	0.18 (−0.02 to 0.39)

Data from 1078 mother-child pairs participating in Project Viva.

[a] Adjusted for maternal age, race and/or ethnicity, education, smoking, parity, and prepregnancy BMI; household income; and child age and sex. Models stratified by race and/or ethnicity do not include race and/or ethnicity as a covariate. Models stratified by sex do not include sex as a covariate.

In secondary analyses, first-trimester sugary beverage intake was not associated with any of the midchildhood outcomes (data not shown). However, change in intake from first to second trimester was associated with all of the outcomes, with effect estimates similar to those for the second trimester alone. For example, adjusted estimates (95% CIs) for each increase in 1 serving per day of SSBs were 0.07 (0.00 to 0.15) for childhood BMI *z* score and 0.19 (0.04 to 0.35) for FMI.

In addition, in substitution analyses, we found that replacing maternal second-trimester SSBs with water, 100% fruit juice, or milk had a greater beneficial effect on child BMI *z* score (−0.07 [−0.15 to 0.01], −0.08 [−0.19 to 0.03], or −0.10 [−0.19 to −0.01] per increment of 1 serving per day, respectively) than did replacing SSBs with diet soda (−0.02 [−0.16 to 0.13]).

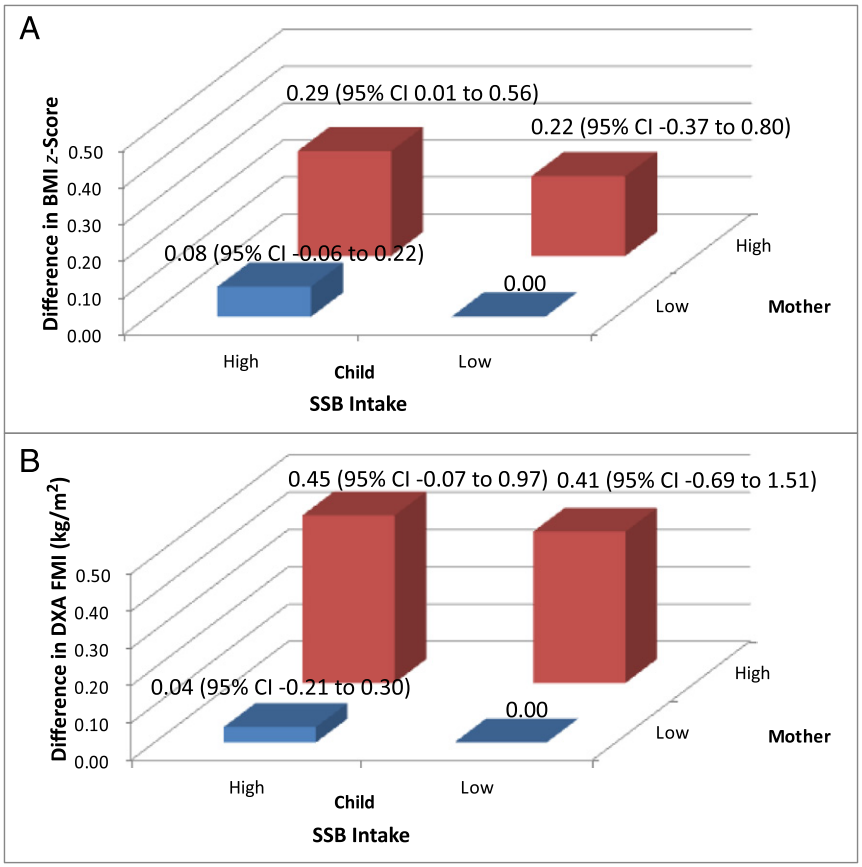

FIGURE 1

Association of the combination of maternal second-trimester (<2 vs ≥2 servings per day) and child (<0.5 vs ≥0.5 servings per week) intake of SSBs with BMI *z* score, A, and DXA FMI, B, in midchildhood. Low mother/low child is the referent group. Estimates are adjusted for maternal age, race and/or ethnicity, education, smoking, parity, and prepregnancy BMI; household income; and child age and sex. Data are from 1078 mother-child pairs participating in Project Viva. *N* = 272 low mother/low child, *N* = 720 low mother/high child, *N* = 13 high mother/low child, and *N* = 73 high mother/high child.

DISCUSSION

In this prospective prebirth cohort study, school-aged children of mothers who consumed more sugary beverages in midpregnancy had higher levels of adiposity, measured by BMI, skinfold thicknesses, and the reference standard DXA. After adjustment for multiple covariates, each additional serving of a sugary beverage consumed by a mother during the second trimester was associated with an additional 0.15 kg/m^2 (95% CI: −0.01 to 0.30) of fat mass. The associations were robust to adjustment for many confounding variables, were independent of the children's beverage intake, and did not differ by child sex or race and/or ethnicity. We did not find associations with intakes of diet soda or water, or with any first-trimester beverage consumption. These findings suggest that efforts to limit SSB consumption once women become pregnant could help stem the tide of childhood obesity.

The paradigm of developmental origins of health and disease posits that cues during early, plastic phases of human development can have lifelong consequences for obesity and chronic disease.[37] Because such cues can determine a trajectory of long-term health, and because plasticity wanes with age, interventions to alter health trajectories become more difficult as fetuses become children and children become adults.[38] Given the combination of physiologic, behavioral, and social barriers, weight control after the onset of obesity is particularly challenging, implying that early prevention is paramount.

Maternal diet during pregnancy, as 1 element of the "fetal supply line," may supply sufficient developmental cues to offer effective prevention of obesity in the offspring. The few animal experiments that address beverage or added sugar consumption in pregnancy provide support for our observations, but they may not directly translate to humans.[39–43] In children and nonpregnant adults, higher consumption of sugary beverages consistently predicts excess weight gain, and randomized trials suggest that reducing their intake can at least modestly contribute to prevention or treatment of obesity.[19–21,44] The human literature on health outcomes related to maternal beverage intake in pregnancy, however, is scant. In the Nurses' Health Study II, consumption of sugar-sweetened cola before pregnancy was associated with risk of developing gestational diabetes, although in a previous Project Viva analysis, we found no relationships between first-trimester glycemic index, glycemic load, carbohydrates, or Western diet pattern (which includes sugary beverages) and development of gestational diabetes.[25,45] In the large Norwegian Mother-Child cohort study and in the smaller Born-in-Bradford study, higher intake of sugary beverages predicted increased risk of preterm birth.[46–48] The Norwegian investigators also reported a direct association between sugary beverage intake and preeclampsia.[49–51] In contrast, in the Danish National Birth Cohort, investigators found no relationship with preterm birth.[52]

In the United States, in an observational analysis of 249 infants whose mothers took part in a randomized controlled trial

of moderating gestational weight gain, Phelan et al[53] found that a greater percent of energy from sweets consumed in early pregnancy predicted higher weight for age among the 6-month-old infants of overweight or obese mothers (N = 121) but not among infants of normal weight mothers (N = 128). Among 66 mother-infant pairs of Hispanic ethnicity in Texas, Watt et al[54] found that maternal sugary beverage intake was directly associated with weight for length exceeding the 85th percentile during infancy. However, in a much larger study of Canadian mother-infant pairs, Azad et al[55] found no association of intake of sugary beverages in late pregnancy with risk of overweight at 1 year of age. In comparison with those 3 studies, the outcomes in our study were in midchildhood, when BMI more strongly predicts adverse adult outcomes.[12,56] We examined substitution as well as addition effects, and we employed direct measures of adiposity in addition to height and weight.

One key question with any study of maternal behavior and offspring health is the extent to which the same behavior in the child explains the findings. Maternal beverage intake could be related to child intake via 3 pathways. First, in the postnatal period, mothers provide food for their children and serve as role models for behaviors.[57] Second, an inherited genetic predilection for certain beverages could exist.[58] Third, maternal intake in pregnancy could program child's intake, perhaps via mechanisms related to "fuel-mediated teratogenesis."[59] Distinguishing among these 3 possibilities is difficult in a single study. Nevertheless, our findings from stratified analyses that indicate that maternal intake was more strongly related to the outcomes than was child intake lend credence to the hypothesis that the observed effects are due to prenatal programming of susceptibility to obesity. In addition, we observed effects for second-trimester beverage intake, when fetal fat accumulation is accelerating, but not for intakes earlier in pregnancy.

Some evidence suggests that artificially sweetened beverages (even those without calories) can lead to increased consumption of food and therefore excess weight gain that is intermediate between unsweetened beverages and SSBs.[60] In both the Norwegian and Danish cohorts, higher consumption of artificially sweetened beverages was associated with increased risk of preterm birth,[47,52] and in the Canadian cohort, with risk of overweight at 1 year of age.[55] However, we did not find that maternal diet soda intake was associated with offspring adiposity.

Strengths of this study include prospective data collection since early pregnancy; robust dietary assessment at 2 points in pregnancy; availability of numerous covariates to address confounding, mediation, and moderation; research-standard adiposity outcomes; and a sample size that allowed precise estimates of effect, at least for continuous outcomes. Limitations include self-report of diet, but resulting misclassification may well be nondifferential leading to bias toward the null, a conservative bias. We did not measure beverage intake in exactly the same way in mothers during pregnancy and in their children, but there was sufficient overlap for consistency, and the 2 were moderately correlated. Loss to follow-up, although regrettable, is common in cohort studies in early life. We observed some differences in baseline covariates between participants and those lost to follow-up, but adjustment for those variables did not alter the conclusions. In addition, we did not observe differences in baseline maternal beverage intake. These factors argue against selection bias as a major threat to validity of the findings.

CONCLUSIONS

Prevention strategies at the earliest stages of human development, including before birth, hold promise for prevention of obesity and noncommunicable diseases across the life course.[37] In this study, we found that mothers who consumed more sugary beverages in midpregnancy had children with greater levels of adiposity. Women may be more amenable to behavior change when they are pregnant than when they are not.[61] Combined with our results, this observation provides impetus to examine the long-term effects of interventions to reduce sugary beverage intake during pregnancy. In the United States, reductions in overall sugary beverage intake over the past decade, combined with hopeful results from some randomized trials of behavior change in pregnant women,[62,63] make efforts to reduce sugary beverages in pregnancy a realistic goal. In low- and middle-income countries, however, where sugary beverage intake continues to rise along with the rapid emergence of obesity, and resources are lacking for individual-level behavior change interventions during gestation, the challenges are great.

ACKNOWLEDGMENTS

We thank the participants and staff of Project Viva.

ABBREVIATIONS

CI: confidence interval
DXA: dual-energy radiograph absorptiometry
FFQ: food frequency questionnaire
FMI: fat mass index
OR: odds ratio
SS: subscapular skinfold thickness
SSB: sugar-sweetened beverage
TR: triceps skinfold thickness

DOI: https://doi.org/10.1542/peds.2017-0031

Accepted for publication May 12, 2017

Address correspondence to Sheryl L. Rifas-Shiman, MPH, Division of Chronic Disease Research Across the Lifecourse, Harvard Medical School and Harvard Pilgrim Health Care Institute, 401 Park Dr, Suite 401, Boston, MA 02215. E-mail: sheryl_rifas@hphc.org

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: Grants from the US National Institutes of Health (R37 HD 034568, R01 HL 064925, R01AI102960, P30 DK092924, UG3 OD023286). 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.

REFERENCES

1. Gillman MW. Developmental origins of obesity. In: Hu FB, ed. *Obesity Epidemiology*. New York, NY: Oxford University Press; 2008:399–415
2. McMillen IC, Robinson JS. Developmental origins of the metabolic syndrome: prediction, plasticity, and programming. *Physiol Rev*. 2005;85(2):571–633
3. Mathias PC, Elmhiri G, de Oliveira JC, et al. Maternal diet, bioactive molecules, and exercising as reprogramming tools of metabolic programming. *Eur J Nutr*. 2014;53(3):711–722
4. Parlee SD, MacDougald OA. Maternal nutrition and risk of obesity in offspring: the Trojan horse of developmental plasticity. *Biochim Biophys Acta*. 2014;1842:495–506
5. Poston L. Maternal obesity, gestational weight gain and diet as determinants of offspring long term health. *Best Pract Res Clin Endocrinol Metab*. 2012;26(5):627–639
6. Muhlhausler BS, Bloomfield FH, Gillman MW. Whole animal experiments should be more like human randomized controlled trials. *PLoS Biol*. 2013;11(2):e1001481
7. Brion MJ, Ness AR, Rogers I, et al. Maternal macronutrient and energy intakes in pregnancy and offspring intake at 10 y: exploring parental comparisons and prenatal effects. *Am J Clin Nutr*. 2010;91(3):748–756
8. Maslova E, Rytter D, Bech BH, et al. Maternal protein intake during pregnancy and offspring overweight 20 y later. *Am J Clin Nutr*. 2014;100(4):1139–1148
9. Murrin C, Shrivastava A, Kelleher CC; Lifeways Cross-generation Cohort Study Steering Group. Maternal macronutrient intake during pregnancy and 5 years postpartum and associations with child weight status aged five. *Eur J Clin Nutr*. 2013;67(6):670–679
10. Okubo H, Crozier SR, Harvey NC, et al. Maternal dietary glycemic index and glycemic load in early pregnancy are associated with offspring adiposity in childhood: the Southampton Women's Survey. *Am J Clin Nutr*. 2014;100(2):676–683
11. Bodnar LM, Siega-Riz AM. A diet quality index for pregnancy detects variation in diet and differences by sociodemographic factors. *Public Health Nutr*. 2002;5(6):801–809
12. Baker JL, Olsen LW, Sørensen TI. Childhood body-mass index and the risk of coronary heart disease in adulthood. *N Engl J Med*. 2007;357(23):2329–2337
13. 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
14. Malik VS, Popkin BM, Bray GA, Després JP, Willett WC, Hu FB. Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes: a meta-analysis. *Diabetes Care*. 2010;33(11):2477–2483
15. Malik VS, Willett WC, Hu FB. Sugar-sweetened beverages and BMI in children and adolescents: reanalyses of a meta-analysis. *Am J Clin Nutr*. 2009;89(1):438–439, author reply 439–440
16. Forshee RA, Anderson PA, Storey ML. Sugar-sweetened beverages and body mass index in children and adolescents: a meta-analysis. *Am J Clin Nutr*. 2008;87(6):1662–1671
17. Mesirow MS, Welsh JA. Changing beverage consumption patterns have resulted in fewer liquid calories in the diets of US children: National Health and Nutrition Examination Survey 2001-2010. *J Acad Nutr Diet*. 2015;115(4):559–566.e4
18. Piernas C, Ng SW, Popkin B. Trends in purchases and intake of foods and beverages containing caloric and low-calorie sweeteners over the last decade in the United States. *Pediatr Obes*. 2013;8(4):294–306
19. de Ruyter JC, Olthof MR, Seidell JC, Katan MB. A trial of sugar-free or sugar-sweetened beverages and body weight in children. *N Engl J Med*. 2012;367(15):1397–1406
20. Ebbeling CB, Feldman HA, Chomitz VR, et al. A randomized trial of sugar-sweetened beverages and adolescent body weight. *N Engl J Med*. 2012;367(15):1407–1416
21. Hu FB. Resolved: there is sufficient scientific evidence that decreasing sugar-sweetened beverage consumption will reduce the prevalence of obesity and obesity-related diseases. *Obes Rev*. 2013;14(8):606–619
22. Gardner DS, Hosking J, Metcalf BS, Jeffery AN, Voss LD, Wilkin TJ. Contribution of early weight gain to

childhood overweight and metabolic health: a longitudinal study (EarlyBird 36). *Pediatrics*. 2009;123(1). Available at: www.pediatrics.org/cgi/content/full/123/1/e67

23. Leibel RL. Molecular physiology of weight regulation in mice and humans. *Int J Obes*. 2008;32(suppl 7):S98–S108
24. Oken E, Baccarelli AA, Gold DR, et al. Cohort profile: Project Viva. *Int J Epidemiol*. 2015;44(1):37–48
25. Chen L, Hu FB, Yeung E, Willett W, Zhang C. Prospective study of pregravid sugar-sweetened beverage consumption and the risk of gestational diabetes mellitus. *Diabetes Care*. 2009;32(12):2236–2241
26. Fawzi WW, Rifas-Shiman SL, Rich-Edwards JW, Willett WC, Gillman MW. Calibration of a semi-quantitative food frequency questionnaire in early pregnancy. *Ann Epidemiol*. 2004;14(10):754–762
27. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. CDC growth charts: United States. *Adv Data*. 2000;(314):1–27
28. Schorr lJ; United Nations National Household Survey Capability Programme. *How to Weigh and Measure Children: Assessing the Nutritional Status of Young Children in Household Surveys*. New York, NY: United Nations Department of Technical Co-operation for Development and Statistical Office; 1986
29. Mueller W, Martorell R. Reliability and accuracy of measurement. In: Lohman T, Roche A, eds. *Anthropometric Standardization Reference Manual*. Champaign, IL: Home Kinetics Books; 1988:83–86
30. Benjamin SE, Rifas-Shiman SL, Taveras EM, et al. Early child care and adiposity at ages 1 and 3 years. *Pediatrics*. 2009;124(2):555–562
31. Huh SY, Rifas-Shiman SL, Rich-Edwards JW, Taveras EM, Gillman MW. Prospective association between milk intake and adiposity in preschool-aged children. *J Am Diet Assoc*. 2010;110(4):563–570
32. Huh SY, Rifas-Shiman SL, Taveras EM, Oken E, Gillman MW. Timing of solid food introduction and risk of obesity in preschool-aged children. *Pediatrics*. 2011;127(3). Available at: www.pediatrics.org/cgi/content/full/127/3/e544
33. Gillman MW, Rifas-Shiman SL, Oken E, Kleinman K, Taveras EM. Change in maternal beverage intake and weight gain from the first to second trimester of pregnancy. In: *The Obesity Society Annual Meeting 2012*; 2012; San Antonio, TX
34. Kleinman KP, Oken E, Radesky JS, Rich-Edwards JW, Peterson KE, Gillman MW. How should gestational weight gain be assessed? A comparison of existing methods and a novel method, area under the weight gain curve. *Int J Epidemiol*. 2007;36(6):1275–1282
35. Li L, Kleinman K, Gillman MW. A comparison of confounding adjustment methods with an application to early life determinants of childhood obesity. *J Dev Orig Health Dis*. 2014;5(6):435–447
36. Pereira MA, Gillman MW. Maternal consumption of artificially sweetened beverages and infant weight gain: causal or casual? *JAMA Pediatr*. 2016;170(7):642–643
37. Gillman MW. Developmental origins of health and disease. *N Engl J Med*. 2005;353(17):1848–1850
38. Godfrey KM, Gluckman PD, Hanson MA. Developmental origins of metabolic disease: life course and intergenerational perspectives. *Trends Endocrinol Metab*. 2010;21(4):199–205
39. Bray GA. Fructose: pure, white, and deadly? Fructose, by any other name, is a health hazard. *J Diabetes Sci Technol*. 2010;4(4):1003–1007
40. Giraudo SQ, Della-Fera MA, Proctor L, Wickwire K, Ambati S, Baile CA. Maternal high fat feeding and gestational dietary restriction: effects on offspring body weight, food intake and hypothalamic gene expression over three generations in mice. *Pharmacol Biochem Behav*. 2010;97(1):121–129
41. Gray C, Long S, Green C, Gardiner SM, Craigon J, Gardner DS. Maternal fructose and/or salt intake and reproductive outcome in the rat: effects on growth, fertility, sex ratio, and birth order. *Biol Reprod*. 2013;89(3):51
42. Regnault TR, Gentili S, Sarr O, Toop CR, Sloboda DM. Fructose, pregnancy and later life impacts. *Clin Exp Pharmacol Physiol*. 2013;40(11):824–837
43. Vickers MH, Clayton ZE, Yap C, Sloboda DM. Maternal fructose intake during pregnancy and lactation alters placental growth and leads to sex-specific changes in fetal and neonatal endocrine function. *Endocrinology*. 2011;152(4):1378–1387
44. Bucher Della Torre S, Keller A, Laure Depeyre J, Kruseman M. Sugar-sweetened beverages and obesity risk in children and adolescents: a systematic analysis on how methodological quality may influence conclusions. *J Acad Nutr Diet*. 2016;116(4):638–659
45. Radesky JS, Oken E, Rifas-Shiman SL, Kleinman KP, Rich-Edwards JW, Gillman MW. Diet during early pregnancy and development of gestational diabetes. *Paediatr Perinat Epidemiol*. 2008;22(1):47–59
46. Borgen I, Aamodt G, Harsem N, Haugen M, Meltzer HM, Brantsæter AL. Maternal sugar consumption and risk of preeclampsia in nulliparous Norwegian women. *Eur J Clin Nutr*. 2012;66(8):920–925
47. Englund-Ögge L, Brantsæter AL, Haugen M, et al. Association between intake of artificially sweetened and sugar-sweetened beverages and preterm delivery: a large prospective cohort study. *Am J Clin Nutr*. 2012;96(3):552–559
48. Petherick ES, Goran MI, Wright J. Relationship between artificially sweetened and sugar-sweetened cola beverage consumption during pregnancy and preterm delivery in a multi-ethnic cohort: analysis of the Born in Bradford cohort study. *Eur J Clin Nutr*. 2014;68(3):404–407
49. Maslova E, Halldorsson TI, Astrup A, Olsen SF. Dietary protein-to-carbohydrate ratio and added sugar as determinants of excessive gestational weight gain: a prospective cohort study. *BMJ Open*. 2015;5(2):e005839
50. Renault KM, Carlsen EM, Nørgaard K, et al. Intake of sweets, snacks and soft

drinks predicts weight gain in obese pregnant women: detailed analysis of the results of a randomised controlled trial. *PLoS One*. 2015;10(7):e0133041

51. Maslova E, Strøm M, Olsen SF, Halldorsson TI. Consumption of artificially-sweetened soft drinks in pregnancy and risk of child asthma and allergic rhinitis. *PLoS One*. 2013;8(2):e57261
52. Halldorsson TI, Strøm M, Petersen SB, Olsen SF. Intake of artificially sweetened soft drinks and risk of preterm delivery: a prospective cohort study in 59,334 Danish pregnant women. *Am J Clin Nutr*. 2010;92(3):626–633
53. Phelan S, Hart C, Phipps M, Abrams B, Schaffner A, Adams A, Wing R. Maternal behaviors during pregnancy impact offspring obesity risk. *Exp Diabetes Res*. 2011;2011:985139
54. Watt TT, Appel L, Roberts K, Flores B, Morris S. Sugar, stress, and the Supplemental Nutrition Assistance Program: early childhood obesity risks among a clinic-based sample of low-income Hispanics. *J Community Health*. 2013;38(3):513–520
55. Azad MB, Sharma AK, de Souza RJ, et al; Canadian Healthy Infant Longitudinal Development Study Investigators. Association between artificially-sweetened beverage consumption during pregnancy and infant body mass index. *JAMA Pediatr*. 2016;170(7):662–670
56. Franks PW, Hanson RL, Knowler WC, Sievers ML, Bennett PH, Looker HC. Childhood obesity, other cardiovascular risk factors, and premature death. *N Engl J Med*. 2010;362(6):485–493
57. Gillman MW, Oliveria SA, Moore LL, Ellison RC. Inverse association of dietary calcium with systolic blood pressure in young children. *JAMA*. 1992;267(17):2340–2343
58. Gugusheff JR, Ong ZY, Muhlhausler BS. The early origins of food preferences: targeting the critical windows of development. *FASEB J*. 2015;29(2):365–373
59. Baack ML, Wang C, Hu S, Segar JL, Norris AW. Hyperglycemia induces embryopathy, even in the absence of systemic maternal diabetes: an in vivo test of the fuel mediated teratogenesis hypothesis. *Reprod Toxicol*. 2014;46:129–136
60. Pereira MA. Diet beverages and the risk of obesity, diabetes, and cardiovascular disease: a review of the evidence. *Nutr Rev*. 2013;71(7):433–440
61. Oken E, Kleinman KP, Berland WE, Simon SR, Rich-Edwards JW, Gillman MW. Decline in fish consumption among pregnant women after a national mercury advisory. *Obstet Gynecol*. 2003;102(2):346–351
62. Vesco KK, Karanja N, King JC, et al. Preliminary outcome data for a weight management program designed to help obese women minimize weight gain during pregnancy: the healthy moms trial. In: *The Obesity Society Annual Meeting 2012*; 2012; San Antonio, TX
63. Vesco KK, Karanja N, King JC, et al. Efficacy of a group-based dietary intervention for limiting gestational weight gain among obese women: a randomized trial. *Obesity (Silver Spring)*. 2014;22(9):1989–1996

Beverage Intake During Pregnancy and Childhood Adiposity

Matthew W. Gillman, Sheryl L. Rifas-Shiman, Silvia Fernandez-Barres, Ken Kleinman, Elsie M. Taveras and Emily Oken

Pediatrics; originally published online July 8, 2017;
DOI: 10.1542/peds.2017-0031

PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Beverage Intake During Pregnancy and Childhood Adiposity

Matthew W. Gillman, Sheryl L. Rifas-Shiman, Silvia Fernandez-Barres, Ken Kleinman, Elsie M. Taveras and Emily Oken

Pediatrics; originally published online July 8, 2017;
DOI: 10.1542/peds.2017-0031

American Academy of Pediatrics
DEDICATED TO THE HEALTH OF ALL CHILDREN™