Received: 8 January 2019 | Revised: 1 July 2019 | Accepted: 15 July 2019
DOI: 10.1111/ijpo.12569

ORIGINAL RESEARCH

WILEY pediatricobesity

Association of breastfeeding and early exposure to sugar-sweetened beverages with obesity prevalence in offspring born to mothers with and without gestational diabetes mellitus

Sarvenaz Vandyousefi MS, RD[1] | Shannon E. Whaley PhD, RD[2] | Elizabeth M. Widen PhD, RD[1] | Fiona M. Asigbee PhD, MPH[1] | Matthew J. Landry BS[1] | Reem Ghaddar BS[1] | Jaimie N. Davis PhD, RD[1]

[1] Department of Nutritional Sciences, The University of Texas, Austin, Texas, USA

[2] Department of Research and Evaluation, Public Health Foundation Enterprises Special Supplemental Nutrition Program for Women, Infants, and Children Program, Irwindale, California, USA

Correspondence
Dr. Jaimie N. Davis, Department of Nutritional Sciences, Dell Pediatrics Research Institute, University of Texas, 1400 Barbara Jordan Blvd., DPRI 3.834, Austin, TX 78723, USA.
Email: jaimie.davis@austin.utexas.edu

Funding information
First 5 LA

Summary

Background: The relationship of gestational diabetes mellitus (GDM), exclusive breastfeeding (EBF), and sugar-sweetened beverages (SSBs) on obesity prevalence in children has rarely been evaluated.

Objective: This study examined the association of GDM status, EBF, and SSB with obesity prevalence in children (1-5 y).

Methods: Data are from the 2014 Los Angeles County WIC Survey, which included 3707 mothers and their children (1-5 y).

Results: Compared with GDM offspring who were not EBF, GDM offspring who were EBF had lower odds of obesity, as did non-GDM offspring who were and were not EBF. Compared with GDM offspring with high-concurrent SSB intake (>3 servings/d) and no EBF, GDM offspring with high SSB intake and EBF did not have lower odds of obesity, whereas those with GDM, low SSB (≤1 serving/d), and EBF had lower odds of obesity. Using non-GDM, EBF, and low SSB as referent, non-GDM offspring who were not EBF, with either high or low SSB, had approximately a fourfold increase in odds of obesity.

Conclusions: In GDM offspring, EBF is only associated with lower obesity levels if later SSB intake is also low, whereas EBF is protective against obesity in non-GDM offspring regardless of high or low later SSBs intake.

KEYWORDS

exclusive breastfeeding, gestational diabetes mellitus, obesity, sugar-sweetened beverages

1 | INTRODUCTION

Childhood obesity has become a serious health concern in the United States especially among Hispanic children. In 2015 and 2016, obesity impacted 18.5% of US children and adolescents (2-19 y of age), 13.9% of whom were preschool-aged children (2-5 y of age).[1] In addition, 12.3% of 3- to 23-month-old infants enrolled in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) in 2014 had high weight for length.[2] Hispanic children and infants have the highest obesity prevalence and weight for length among all racial/ethnic groups, respectively.[1,2] Many prenatal and early life factors such as in utero exposure to gestational diabetes mellitus

(GDM) and early life infant feeding may contribute to higher weight gain, obesity, and related metabolic complications in children.[3,4]

Gestational diabetes mellitus, defined as "any degree of glucose intolerance with onset or first recognition during pregnancy," is one of the most common metabolic complications of pregnancy worldwide.[5] In 2017, one in seven women was diagnosed with GDM.[6] Hispanic women had consistently higher prevalence and risk of GDM (9.3%) than non-Hispanic white (NHW) women (7.0%) in the United States between 2007 and 2014.[7] Intrauterine exposure to GDM is known as one of the contributing factors to childhood obesity in offspring.[8] Several researchers have shown that women with GDM are less likely to exclusively breastfeed in the first hour postpartum and more likely to formula feed their children in the hospital than women without GDM.[9,10]

Breast milk has been recognized as the best food for infants to meet their daily nutrients and energy requirements for the first 6 months after birth.[11] Numerous studies have shown that lower breastfeeding (BF) duration and intensity increase the likelihood of overweight and obesity in children.[12-14] While exclusive BF (EBF), feeding infants exclusively with breast milk and no other liquids or solids, for at least 6 months after birth is recommended,[11,15] only about 25% of US infants were exclusively breastfed for 6 months in 2014 and 2015.[16] Hispanics and African Americans have lower rates of EBF than NHW mothers in the United States.[17] There is an increasing evidence that BF has a protective effect against obesity in offspring; however, the impact of EBF in offspring exposed to GDM is not well studied or understood.

Mounting evidence points to sugar consumption, in particular sugar-sweetened beverages (SSBs), as a key modifiable factor contributing to obesity and related metabolic disorders.[18-21] A few studies have reported that children who were breastfed and had limited exposure to SSBs had lower obesity prevalence compared with those not breastfed and had higher intake of SSBs.[19,22] While some of the mentioned studies controlled for GDM status, these studies did not examine the interaction effect of GDM with early SSBs intake in children (1-5 y of age) on obesity prevalence. To date, no study has examined the relationships of EBF, SSBs intake, and GDM status on obesity prevalence in offspring (1-5 y of age). Therefore, the goal of this study was to examine the individual and interaction effects of EBF, SSB intake, and GDM status on obesity prevalence. The current study hypothesized that GDM, EBF, and later SSBs intake would be independently associated with lower odds of obesity in offspring and that there would be an interaction between these three factors, with the lowest prevalence of obesity in the group with no GDM, EBF, and low SSB intake.

2 | METHODS

Data for this study are from the 2014 Los Angeles County (LAC) WIC Survey, the triennial WIC household survey adapted from the 2005 LAC Health Survey,[23] which was designed to assess health-related information, early life infant feeding, and home and community indicators of support for women, infants, and children under age 5 residing in LAC.[24] Data on maternal GDM status, child's birth weight, EBF, and frequency of SSBs intake were collected via a parental telephone survey.[25] Although the 2014 survey of LAC WIC parents' questionnaire included 127 questions, the current study analysed data on questions related to early life infant feeding practices of offspring, GDM status, demographics, ethnic and racial background of the child, and obesity measures.[26]

For this study, eligible participants were (a) biological mother of a child enrolled in the WIC programme, (b) delivered a full-term baby (excluded if delivered a premature or low birth weight), and (c) completed the infant feeding survey questions. If a family reported more than one WIC eligible child, then data were collected based on the child with the most recent birthdate.[12] Overall, 5000 women and their children (prenatal women through 5-year-olds) participated in LAC WIC 2014; however, this study only included 3707 children (1-5 y of age), and about 470 (or approximately 13%) of them were born to mothers with GDM.[27] About 1300 participants were excluded from the current analysis because they were pregnant with no children, had infants younger than 1 year of age, or had missing data.

2.1 | GDM and early life feeding measures

The current study examined EBF, defined as feeding infants exclusively with breast milk and no other liquids or solids, for at least 6 months after birth. The following survey questions were asked from the mothers to determine EBF duration: "How old was your child the first time (he) (she) was given formula?," "Are you currently breast-feeding your child?," "How old was your child when you completely stopped breastfeeding (him/her)?," and "How old was your child the first time (he/she) was given anything besides breast milk? This includes formula, baby food, juice, cow's milk, sugar water or anything else you fed your baby." Responses for the last question were "less than 1 week, 1 week but less than 1 month, 1 month but less than 3 months, 3 months but less than 6 months, at 6 months, or have you not fed your baby anything besides breast milk, more than 6 months."

Gestational diabetes mellitus status was analysed as categorical variables (ie, "no GDM" who were born to mothers without GDM vs "GDM" who were born to mothers with GDM). To analyse GDM-BF interaction, children were divided into four categories based on GDM and EBF status: (a) mothers without GDM who EBF (ie, "non-GDM, EBF"), (b) mothers without GDM who did not EBF (ie, "non-GDM, no-EBF"), (c) mothers with GDM who EBF (ie, "GDM, EBF"), and (d) mothers without GDM who did not EBF (ie, "GDM, no-EBF").

Sugar-sweetened beverages variable coding included all SSBs (excluding 100% fruit juice, diet sodas, and sugar-free drinks) and chocolate or flavoured milk reported at the timing of survey of LAC WIC parent questionnaire (child 1-5 y of age). SSBs frequency of intake was divided into tertiles to create three equal groups as categorical variables (ie, low SSB [≤1 serving/d], medium SSB [>1 and ≤3 servings/d], and high SSB [>3 servings/d]).[26] This dietary screener was previously tested to assess reliability and validity of sweetened foods and beverages intake among children (2-4 y of age) against three 24-hour recalls in a subsample of 70 primarily Hispanic mothers.[28] Intraclass correlation coefficient (ICC) for total SSB (excluding milk, chocolate milk, and 100% fruit juice) yielded to 0.7 (ie, moderate agreement), and for chocolate or sweetened milk yielded to 0.84 (ie, substantial agreement). Spearman's rank correlations coefficient (SCC) for total SSB (excluding milk, chocolate milk, and 100% fruit juice) yielded to 0.46 (ie, moderate), and for chocolate or sweetened milk yielded to 0.57 (ie, strong).

2.2 | Anthropometrics

To overcome the challenges of accurately assessing a young child's height and weight in a phone survey, survey records were linked to WIC administrative data to obtain accurate anthropometric data for the target children. Children were weighed and measured every 6 months by WIC staff. Height, weight, and body mass index (BMI) measurements of children aged 2 to 5 years obtained by WIC staff were previously validated against the standard measurements taken by research staff. Sensitivity and specificity of WIC BMI percentile classifications (ie, overweight/obese versus underweight/normal) were high at 86% and 92%, respectively, indicating that WIC staff can accurately measure anthropometrics.[29]

2.3 | Definition of obesity

Infants (1-2 y of age) with weight for height more than or equal to 97.7th percentile were classified as high weight for length.[30] Children (2-5 y of age) were classified as subjects with obesity if their BMI for age was more than or equal to 95th percentile, with overweight if their BMI for age was more than or equal to 85th percentile,[31] and at risk of overweight if their BMI for age was more than or equal to 75th percentile.

2.4 | Statistical analysis

Summary statistics, graphical analyses, and frequency distributions were used to describe the data. Descriptive statistics (ie, mean, standard deviation, range, median and quartiles, histograms, and Q-Q plots) assessed the distribution of the data. First, *t* test and chi-square analyses were performed to assess differences in baseline and physical characteristics between GDM and non-GDM offspring. Next, binary logistic regressions evaluated the individual and interaction effects of BF, GDM, and SSBs intake on the prevalence of obesity while controlling the following covariates: child's age, sex, and race/ethnicity. The dependent variable was obese status; ie, children with obesity (either high weight for length for 1-2 y or BMI percentile ≥95th for 2-5 y) were compared with nonobese children. If the interactions with GDM were significant, then the group with the least desirable condition was selected as the referent group for Bonferroni post hoc comparisons (ie, GDM offspring who were not EBF and high SSBs intake). All analyses were performed using SAS version 9.4 (SAS, North Carolina, USA). A P value of.05 was used to denote significance.

3 | RESULTS

A total of 3707 children (1-5 y of age) were eligible for this analysis. Of these participants, 3310 had complete data on all variables. About 81% of the participants were of Hispanic origin, 13% (n = 470) were exposed to GDM in utero, 27% (n = 924) were exclusively breastfed for at least 6 months, and 23% (n = 865) were high SSBs consumers. Physical characteristics, GDM status, EBF, and overweight and obesity rates of the participants are shown in Table 1. There were no differences in age and sex between GDM and non-GDM participants. Half of the children were male with an average age of 3 years at the time their mother was surveyed. Although GDM offspring had higher birth weight, this difference was not significant. Non-GDM offspring were taller than those born to mothers with GDM (P = .05). Hispanics had significantly higher rates of GDM (P = .007) compared with other ethnicities. Compared with non-GDM offspring, GDM offspring had similar rates of EBF (25% vs 27%; P = .13) but had higher rates of obesity (18% vs 29%; P < .0001). Consumption of SSBs did not differ between the two groups.

Results from the logistic regression for obesity prevalence are shown in Table 2. Nineteen percent of children had either high weight for length (BMI percentile ≥97.7th percentile; 1-2 y of age) or obesity (BMI for age percentile ≥95th; 2-5 y of age). Males were more likely to have obesity than females. However, there were no differences between males and females with BMI for age more than or equal to 85th and 75th percentiles. Birth weight and age were not significant in the model. Hispanics, 1 to 5 years of age and 2 to 5 years of age, were 62% and 46% more likely to have obesity compared with NHW children (both P < .01). Results were consistent with findings in children with overweight and at risk of overweight. GDM offspring compared with non-GDM offspring (both 1-5 y of age and 2-5 y of age) were more likely to have obesity (odds ratio [OR] = 1.72; 95% CI, 1.36-2.19, P < .0001; OR = 2.47; 95% CI, 1.73-3.54, P < .0001). Similarly, 2- to 5-year-old children who were exposed to GDM in utero were more likely to have BMI for age more than or equal to 85th and more than or equal to 75th percentiles compared with non-GDM offspring (OR = 2.0; 95% CI, 1.55-2.70, P < .0001; OR = 1.67; 95% CI, 1.27-2.19, P < .0001).

Children (1-5 y of age and 2-5 y of age) who were EBF had lower odds of obesity than those who were not EBF (OR = 0.39; 95% CI, 0.31-0.49, P < .0001; OR = 0.40; 95% CI, 0.28-0.58, P < .0001). SSBs intake was independently associated with obesity prevalence in both age categories (P = .03 and P = .04). However, there was no significant association between SSBs intake and having BMI for age more than or equal to 85th and more than or equal to 75th percentiles. Children 1 to 5 years of age who were low SSB consumers (≤1 SSB serving/d) compared with high SSB consumers (>3 SSB servings/d) had lower odds of obesity (OR = 0.22; 95% CI, 0.05-0.92, P = .04), whereas the

TABLE 1 Comparison of physical characteristics between GDM and non-GDM children participating at LAC WIC[a]

Variable[a]	Total (n = 3707)	Non-GDM (n = 3237)	GDM (n = 470)	*P* Value[b]
Male, n (%)	1906.0 (51.4)	1662.0 (51.3)	244.0 (51.9)	.84
Age, y	2.9 ± 1.2	2.9 ±1.2	2.9 ±1.2	.07
Birth weight, kg	3.4 ±1.8	3.3 ±1.6	3.5 ±2.0	.11
Weight, kg	13.8 ±3.9	13.8 ±3.8	13.7 ±4.1	.52
Height, cm	88.8 ± 12.2	88.9 ±12.2	87.7 ±12.4	.05
Child's ethnicity, n (%)				
Hispanics	3011.0 (81.2)	2602.0 (80.4)	409.0 (87.0)	**.007**
Non-Hispanic white	122.0 (3.3)	112.0 (3.5)	10.0 (2.1)	
African American	255.0 (6.9)	233.0 (7.2)	22.0 (4.7)	
Asian Pacific Islander	88.0 (2.4)	76.0 (2.3)	12.0 (2.6)	
Other	231.0 (6.2)	214.0 (6.6)	17.0 (3.6)	
Overweight/obesity status, n (%)				
1-2 y of age				
High weight for length ≥987.7th percentile	236.0 (24.2)	199.0 (24.1)	37.0 (28.5)	.27
2-5 y of age				
At risk of overweight (≥75th to <85th percentiles)	326.0 (12.6)	230.0 (10.1)	41.0 (12.9)	**<.0001**
Overweight (≥85th to <95th percentiles)	372.0 (14.4)	325.0 (14.3)	47.0 (14.8)	
Obesity (≥95th percentile)	502.0 (19.4)	410.0 (18.0)	92.0 (28.9)	
Exclusive breastfeeding status, n (%)				
<6 mo	2505.0 (72.6)	2195.0 (72.8)	322.0 (74.8)	.13
≥6 mo	946.0 (27.4)	820.0 (27.2)	126.0 (25.2)	
SSBs frequency intake, n (%)				
SSB ≤ 1 serving/d	1184.0 (31.9)	1032.0 (31.9)	152.0 (32.3)	.24
1 < SSB ≤ 3 servings/d	1579.0 (42.6)	1373.0 (42.4)	206.0 (43.8)	
SSB > 3 servings/d	865.0 (23.3)	765.0 (23.6)	100.0 (21.3)	

Note. Significant *P* values (<.05) are bolded.

Abbreviations: GDM, gestational diabetes mellitus; LAC WIC, Los Angeles County women, infants, and children; SSBs, sugar-sweetened beverages.

[a]Values are mean ± SD unless otherwise stated.

[b]The *t* test and chi-square test were run to assess difference in means or % between non-GDM and GDM groups.

Bonferonni comparison was attenuated to a trend (*P* = .09) for children 2 to 5 years of age.

There was an overall significant EBF-GDM interaction on the prevalence of obesity among 1- to 5-year-old (*P* = .03) and 2- to 5-year-old children (*P* = .04). However, the interaction effect was attenuated to a trend when we only examined the 2- to 5-year-old children with overweight and at risk of overweight. In 1- to 5-year-olds, compared with GDM children who were not EBF (referent), GDM children who were EBF had lower odds of obesity (OR = 0.56; 95% CI, 0.33-0.95, *P* = .03). Compared with GDM children not EBF, non-GDM children who were EBF or not EBF both had lower odds of obesity prevelance (OR = 0.65; 95% CI, 0.50-0.85, *P* = .001; OR = 0.21; 95% CI, 0.15-0.30, *P* < .0001). In the 2- to 5-year-old children, compared with GDM children not EBF, GDM children who were EBF had lower odds of obesity (OR = 0.57; 95% CI, 0.33-0.99, *P* = .04). Compared with the referent group, non-GDM children who were EBF or not EBF both had lower odds of obesity prevelance (OR = 0.54; 95% CI, 0.40-0.73, *P* < .001, and OR = 0.17; 95% CI, 0.11-0.25, *P* < .0001). Figure 1 displays the odds of obesity by EBF-GDM groups among all 1- to 5-year-old children.

The current study found no significant GDM-SSBs interaction on the prevelance of obesity among 1- to 5-year-old (*P* = .26) and 2- to 5-year-old children (*P* = .97). However, there was a significant GDM-EBF-SSBs interaction on obesity prevalence among 1- to 5-year-olds (*P* = .02). This relationship was attenuated for all 2- to 5-year-old groups (*P* > .05). Bonferroni post hoc comparisons for GDM-EBF and GDM-EBF-SSBs interactions are further displayed in Table 3.

In the 1- to 5-year-old children, compared with GDM offspring with low SSBs intake, and who were EBF (referent), those who were GDM with high SSBs intake and EBF had approximately a fivefold increase in odds of obesity (OR = 4.77; 95% CI, 1.55-8.60, *P* = .03). Compared with the GDM referent group, GDM offspring who were

TABLE 2 Logistic regression of physical and early life predictors on the prevalence of obesity—main effects

Predictors	1-5 Y of Age (n = 3310) Obesity[a] *P**	OR[b] (95% CI)	2-5 Y of Age (n = 2427) BMI Percentile ≥95th *P**	OR[b] (95% CI)	BMI Percentile ≥85th *P**	OR[b] (95% CI)	BMI Percentile ≥75th *P**	OR[b] (95% CI)
Sex								
Female	Referent	1.00	-	1.00	-	1.00	-	1.00
Male	**.02**	1.21 (1.01-1.40)	**.04**	1.22 (1.00-1.48)	.67	1.04 (0.87-1.23)	.92	0.99 (0.85-1.17)
Age	.14	0.95 (0.89-1.02)	.07	1.15 (1.03-1.29)	.05	1.19 (1.07-1.31)	.07	1.16 (1.05-1.37)
Race								
Non-Hispanics	Referent	1.00	-	1.00	-	1.00	-	1.00
Hispanics	**.0002**	1.62 (0.99-1.04)	**.007**	1.46 (1.11-1.94)	**.001**	1.51 (1.18-1.93)	**.02**	1.29 (1.03-1.61)
GDM								
No	Referent	1.00	-	1.00	-	1.00	-	1.00
Yes	**<.0001**	1.72 (1.36-2.19)	**<.0001**	2.47 (1.73-3.54)	**<.0001**	2.05 (1.55-2.70)	**<.0001**	1.67 (1.27-2.19)
Exclusive breastfeeding (EBF)								
No EBF (<6 mo)	Referent	1.00	-	1.00	-	1.00	-	1.00
EBF (≥6 mo)	**<.0001**	0.39 (0.31-0.49)	**<.0001**	0.40 (0.28-0.58)	**.001**	0.63 (0.48-0.83)	**.007**	0.69 (0.52-0.90)
SSBs intake	**.03**	-	**.04**	-	.44	-	-	-
SSB > 3 servings/d	Referent	1.00	-	1.00	-	-	-	-
1 < SSB ≤ 3 servings/d	.68	0.78 (0.25-2.47)	.66	0.76 (0.23-2.53)	.66	-	-	-
SSB ≤ 1 serving/d	**.04**	0.22 (0.05-0.92)	.09	0.26 (0.05-1.28)	.09	-	-	-

Abbreviations: EBF, exclusive breastfeeding; GDM, gestational diabetes mellitus; SSBs, sugar-sweetened beverages.

[a]Obesity = high weight for length/BMI percentile ≥97.7th (1-2 y) + BMI percentile ≥95th (2-5 y).

[b]OR: odds ratio.

*$P < .05$ (significant *P* values are bolded).

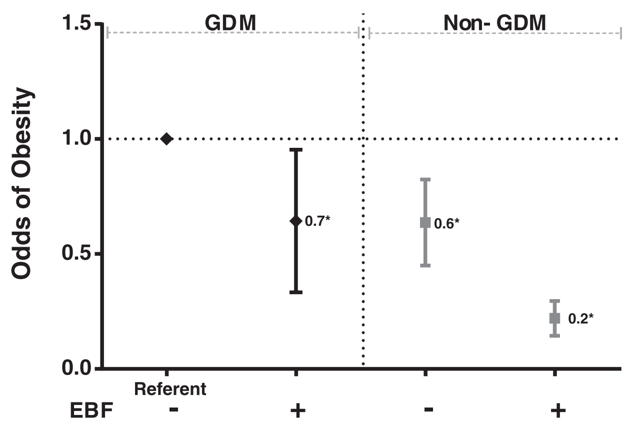

FIGURE 1 Obesity prevalence among 1- to 5-year-old children by gestational diabetes mellitus–exclusive breastfeeding (GDM-EBF) groups. *Significantly lower odds compared with referent

not EBF with low and high SSBs intake had 4.3 and 4.4 times higher odds of obesity, respectively (OR = 4.33; 95% CI, 1.42-8.07, *P* = .01; OR = 4.38; 95% CI, 1.39-8.16, *P* = .01). Using non-GDM, EBF, and low SSB as referent, those who were not EBF with either high or low SSBs had approximately a fourfold increase in odds of obesity (OR = 3.62; 95% CI, 2.16-6.05, $P < .0001$; OR = 3.83; 95% CI, 2.26-6.48, $P < .0001$). Compared with the non-GDM referent group, those who were EBF and had high SSBs intake had 77% higher odds of obesity (OR = 1.77; 95% CI, 0.93-3.37, *P* = .001). Figure 2 exhibits the odds of obesity by EBF-GDM-SSBs groups among all 1- to 5-year-old children.

4 | DISCUSSION

This study replicated numerous studies before, showing that being exposed to GDM in utero is a contributing factor to childhood obesity.[32-34] A study of 33 893 mothers and their offspring (birth—7 y of age) in the United States found that the odds of childhood obesity were 1.45-fold higher for children born to mothers with GDM versus without GDM.[35] Similarly, a retrospective study of 7355 children (mean age of 5.8 y) born to mothers with GDM in Germany found that the odds of childhood overweight (OR = 1.81) and obesity (OR = 2.80) were higher for offspring of mothers with GDM, compared with non-GDM group.[36] The current study found that GDM offspring had 1.72 times higher odds of obesity than non-GDM offspring.

The mechanisms by which the risk of obesity in offspring increases by intrauterine exposure to diabetes are not fully understood. Exposure to maternal diabetes is associated with excess foetal growth in utero, possibly due to foetal hormonal alterations and perturbations in foetal fat accretion. Dabelea et al[37] found that exposure to maternal

TABLE 3 Logistic regression of physical and early life predictors on the prevalence of obesity—interaction effects

	1-5 Y of Age (n = 3310)		2-5 Y of Age (n = 2427)	
	Obesity[a]		BMI Percentile ≥95th	
Predictors	*P**	OR[b] (95% CI)	*P**	OR[b] (95% CI)
GDM-EBF interaction	**.03**	-	**.02**	-
GDM, no EBF	Referent	1.00	-	1.00
GDM, EBF	**.03**	0.56 (0.33-0.95)	**.04**	0.57 (0.33-0.99)
Non-GDM, no EBF	**.001**	0.65 (0.50-0.85)	**<.001**	0.54 (0.40-0.73)
Non-GDM, EBF	**<.0001**	0.21 (0.15-0.30)	**<.0001**	0.17 (0.11-0.25)
GDM-SSBs interaction	.26	-	.97	-
GDM-EBF-SSBs interactions	**.02**	-	.14	-
Non-GDM, EBF, low SSB	Referent	1.00	-	-
Non-GDM, EBF, high SSB	**.001**	1.77 (1.03-3.37)	-	-
Non-GDM, no EBF, low SSB	**<.0001**	3.62 (2.16-6.05)	-	-
Non-GDM, no EBF, high SSB	**<.0001**	3.83 (2.26-6.48)	-	-
GDM, EBF, low SSB	Referent	1.00	-	-
GDM, EBF, high SSB	**.03**	4.77 (1.55-8.60)	-	-
GDM, no EBF, low SSB	**.01**	4.33 (1.42-8.07)	-	-
GDM, no EBF, high SSB	**.01**	4.38 (1.39-8.16)	-	-

Abbreviations: EBF, exclusive breastfeeding; GDM, gestational diabetes mellitus; SSBs, sugar-sweetened beverages.

[a]Obesity = high weight for length/BMI percentile ≥97.7th (1-2 y) + BMI percentile ≥95th (2-5 y).

[b]OR: odds ratio.

**P* < .05 (significant *P* values are bolded).

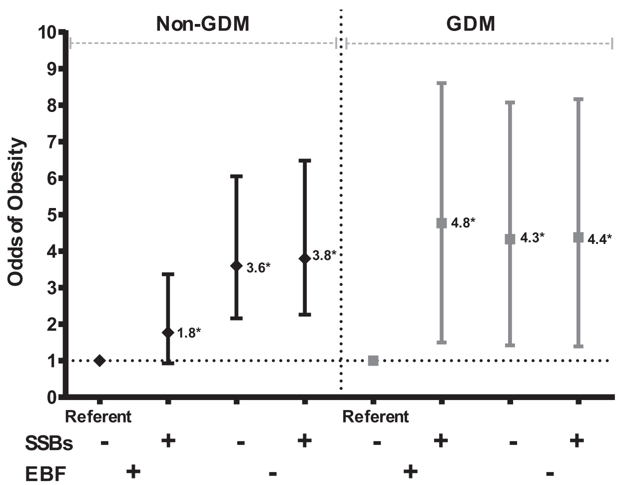

FIGURE 2 Obesity prevalence among 1- to 5-year-old children by gestational diabetes mellitus–exclusive breastfeeding–sugar-sweetened beverages (GDM-EBF-SSBs) groups. *Significantly higher odds compared with referent

GDM in utero results in elevated leptin synthesis, hyperglycaemia, and hyperinsulinemia in offspring. Moreover, maternal prenatal GDM may also influence and alter the expression of genes that direct the accumulation of body fat or related metabolism in fetus.[37]

The current study found a significant interaction effect of GDM and EBF on obesity prevalence and showed that within GDM offspring, those who were EBF compared with those not EBF had 44% lower odds of obesity prevalence. Our results are consistent with the findings of other studies. A clinical cohort of 15 710 mothers and their offspring in the United States found an inverse association between BF and childhood overweight in 2-year-old children who were breastfed for at least 6 months regardless of GDM status of their mothers. Although GDM was not independently associated with childhood overweight, it had no effect on the inverse relationship of BF with overweight prevalence when included in the model.[32] Of note, the above study examined only overweight status of 2-year-old children without differentiating EBF from mixed BF. A retrospective study of 2295 children (2-4 y of age) of Hispanic mothers with GDM during pregnancy showed that offspring who were breastfed for at least 12 months had a 72% decrease in obesity prevalence.[27] The only longitudinal study with quantitative assessment of breast milk intake was conducted by Gunderson et al and showed that greater BF intensity and duration throughout the first 12 months of life were protective against ponderal growth and weight gain among children (birth—12 mo of age) of mothers with GDM.[38]

In contrast to the current findings and findings of the above studies, a prospective cohort of 1152 Asian women with GDM (n = 181) in Singapore reported that offspring of mothers without GDM who were breastfed for at least 4 months had slower growth rate from birth to 36 months of age than those who were not breastfed or were BF for less than 4 months; however, they did not find similar results in offspring of mothers with GDM.[39] In the GDM offspring, greater breast milk intake was associated with accelerated weight gain and BMI in the first 6 months of age. Of note, this study did not differentiate exclusive and predominant (full) BF groups, which might explain their conflicting findings. Similarly, a study of 112 infants (0-2 y of age) born to mothers with GDM by Rodekamp et al showed a significant association between EBF (any duration) and increased childhood relative body weight and blood glucose at 2 years of age; however, after adjustment for the volume of breast milk consumed during the first week of life, all these associations were eliminated.[40]

Research is sparse on the relationship among GDM status, EBF, and childhood obesity, and very little is understood about the composition of breast milk in women with diabetes during pregnancy. In a prospective longitudinal study, Logan et al used magnetic resonance imaging (MRI) and spectroscopy to determine adipose tissue (AT) quantity and distribution and intrahepatocellular lipid (IHCL) content of 86 infants over the first 12 postnatal weeks and found that GDM offspring who were EBF had significantly greater total AT volume at 10 weeks than infants of non-GDM women. However, they found no significant differences between AT distribution and IHCL content of GDM and non-GDM groups at 11-day or 10-week postpartum.[41] Human milk oligosaccharides (HMOs) are one of the key components in human milk that may protect against chronic diseases. Although evidence linking HMOs to childhood obesity is inconclusive, HMOs are known to serve as a fuel for human milk microbiota and help develop healthy gut microbiome in breastfed infants. The gut microbiota affects regulation of the expression of genes that are involved in fat metabolism and deposition and is linked to reduced obesity rates in children.[42] No differences between the total HMOs in breast milk of women with and without GDM have been reported.[43] Therefore, it is unknown whether milk of mothers with GDM can be protective against obesity in offspring, and more research on other components such as leptin and insulin levels in the breast milk of women with GDM is required.

The current study findings are consistent with other studies and showed that children (1-5 y of age) who were EBF for at least 6 months and had low SSBs intake (ie, ≤1 serving/d) had lower odds of obesity than those with high SSBs intake (ie, >3 servings/d) regardless of GDM status of their mothers throughout pregnancy. In a 10-year longitudinal cohort of over 200 Hispanic adolescents as they traverse through puberty (8-19 y of age), high SSBs intake had consistently been linked to increased adiposity and type 2 diabetes risk factors.[44,45] Davis et al found that the combination of BF more than or equal to 12 months and limited exposure to SSBs intake was linked to a 65% reduction in obesity prevalence in 2300 primarily Hispanic children (2-4 y of age) participating in WIC clinics in Los Angeles, CA.[22] In another separate cohort of 1483 primarily Hispanic children (2-4 y of age) participating in WIC, children who were not breastfed and consumed more than or equal to two SSBs per day had 60% higher obesity rates compared with children breastfed for more than or equal to 12 months and had no SSBs intake.[19] Similarly, in a longitudinal study of low-income African American children (3-5 y of age), SSBs intake was positively associated with 10% to 20% increase in the prevalence of obesity after 2 years.[46]

Of note, all of the above studies simply controlled for GDM status of mothers and did not examine the interaction of SSB, GDM, and EBF. To our knowledge, this is the first study that has examined the relationship among GDM status, EBF, and early exposure to SSBs and their independent associations with obesity prevalence in children (1-5 y of age). Our results showed a significant GDM-EBF-SSBs interaction. In non-GDM offspring (1-5 y of age), EBF was protective against odds of obesity in both high and low SSBs consumers; however, EBF was more protective against obesity in low SSBs consumers. In GDM offspring, EBF was only protective against obesity when SSBs intake was low. Surprisingly, GDM offspring that were EBF and had high SSBs consumption had similar fourfold to fivefold increase in odds of obesity compared with those not EBF with either low or high SSBs intake. These results suggest that interventions should focus on the combined protective effects of EBF and low SSBs intake particularly in GDM offspring.

The current study findings were attenuated to a trend for the GDM-EBF and GDM-EBF-SSBs interactions in those with overweight and at risk of overweight (2-5 y of age). These findings suggest that the adverse effects of the SSB may be more of an issue for children with obesity and those with overweight or at risk of overweight are not as adversely impacted by SSB intake. When examining frequency of SSB per obese/overweight/at risk categories in this age range, the frequencies were very similar across the groups (2.6-2.7 SSB frequency/d); however, the EBF within these weight categories did vary (all $P < .01$), 17% EBF for children with obesity, 25% EBF for children with overweight, and 35% EBF for children at risk of overweight. This might suggest that higher EBF intake in those with overweight or at risk of overweight may have shielded them from the adverse effects of later SSB intake, and this might explain why there was no significant GDM-EBF-SSBs interaction effect in children (2-5 y of age) with overweight or at risk of overweight. In addition, the proximity of EBF and GDM in the younger sample (1-2 y of age) could explain why the interaction effects were more significantly linked to obesity in the 1- to 5-year-olds.

In addition, while there were over 2400 children included in these analyses with older children (2-5 y of age), after dividing the sample into GDM, EBF, and SSB intake subgroups, some of those sample sizes were small, with the lowest being GDM offspring, EBF, and high SSB (n = 17). The smaller sample sizes could have resulted in some of the null findings in this older age group.

There are several limitations of the current study to consider. The study sample included predominantly Hispanic participants; therefore, the findings may not be applicable to other populations. Replication of this study using heterogenous populations is warranted. Another limitation of the current study is that height and weight of some of the participants were measured several months apart from their interview date; therefore, BMI status may not be reflective of their BMI at the date of the interview. EBF was retrospectively collected on children

1 to 5 years of age, while height and weight measures were collected on the children at a later visit, when the child was between the ages 1 and 5 years. Therefore, the proximity of EBF and GDM in the younger sample (1-2 y of age) might explain why some of the interaction effects were attenuated to a trend in children 2 to 5 years of age. The attenuated GDM-EBF-SSBs interaction for 2- to 5-year-olds might be due to the smaller sample size and because of the several GDM-EBF-SSBs categories.

The current study also did not account for GDM mothers receiving treatment, and the severity of the GDM was not known. The current study did not assess maternal or paternal BMI, parity, or type of delivery mode for this study, all of which play a role in subsequent obesity and metabolic disease risk in the offspring. In addition, GDM status was self-reported and was not confirmed with medical records; however, validity research has shown self-reported GDM status to be accurate with 94% of self-reported GDM cases confirmed by a physician.[47]

This is the first study, to our knowledge, that assessed the interaction effects of EBF, SSBs intake, and GDM on the prevalence of obesity in predominantly Hispanic children. This study found that exposure to GDM and high SSB intake are independently associated with higher risk of obesity whereas EBF is independently associated with lower risk of obesity. This study also found that within GDM offspring, EBF is only associated with lower obesity levels if SSB intake is also low, whereas EBF is protective against obesity in non-GDM offspring regardless of high or low SSBs intake. These findings highlight the need for interventions targeting mothers with and without GDM to focus on promoting EBF and limiting SSBs intake in their children during early childhood. Although EBF was associated with lower adds of obesity in offspring exposed to GDM in utero, this study suggests that the combination of EBF and low SSBs intake is still needed to combat childhood obesity.

FINANCIAL DISCLOSURE

The authors have indicated that they have no financial relationships relevant to this article to disclose. The authors declare no support from any organization for the submitted work, no financial relationships with any organizations that might have an interest in the submitted work in the previous 3 years, and no other relationships or activities that could appear to have influenced the submitted work.

ACKNOWLEDGEMENTS

Funding for this study was provided by First 5 LA.

CONFLICT OF INTERESTS

The authors have no conflict of interests relevant to this article to disclose.

AUTHORS' CONTRIBUTIONS

Ms. Sarvenaz Vandyousefi and Dr. Jaimie N. Davis contributed to the acquisition of data, conceptualized the analysis plan, carried out the initial analyses, coordinated the interpretation of results, drafted the initial manuscript, and finalized the manuscript. Dr. Shannon E. Whaley collected data, carried out the initial analyses, and critically reviewed and revised the manuscript for important intellectual content. Dr. Elizabeth M. Widen, Dr. Fiona M. Asigbee, Matthew J. Landry, and Reem Ghaddar critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

ORCID

Sarvenaz Vandyousefi https://orcid.org/0000-0002-1006-4054
Matthew J. Landry https://orcid.org/0000-0003-2285-7702
Jaimie N. Davis https://orcid.org/0000-0002-9103-696X

REFERENCES

1. Hales CM, Fryar CD, Carroll MD, Freedman DS, Ogden CL. Trends in obesity and severe obesity prevalence in us youth and adults by sex and age, 2007-2008 to 2015-2016. *JAMA*. 2018;319(16):1723-1725.
2. Freedman DS, Sharma AJ, Hamner HC, et al. Trends in weight-for-length among infants in WIC from 2000 to 2014. *Pediatrics*. 2017;139(1):e20162034.
3. Vandyousefi S, Goran MI, Gunderson EP, et al. Association of breastfeeding and gestational diabetes mellitus with the prevalence of prediabetes and the metabolic syndrome in offspring of Hispanic mothers. *Pediatr Obes*. 2019;14(7):e12515.
4. Wahlqvist ML, Krawetz SA, Rizzo NS, et al. Early-life influences on obesity: from preconception to adolescence. *Ann N Y Acad Sci*. 2015;1347(1):1-28.
5. American Diabetes Association. 2. Classification and diagnosis of diabetes: standards of medical care in diabetes—2018. *Diabetes Care*. 2018;41(suppl 1):S13-S27.
6. Gestational diabetes. International Diabetes Federation; 2018. https://www.idf.org/our-activities/care-prevention/gdm.
7. Casagrande SS, Linder B, Cowie CC. Prevalence of gestational diabetes and subsequent type 2 diabetes among U.S. women. *Diabetes Res Clin Pract*. 2018;141:200-208.
8. Dabelea D, Sauder KA. Intrauterine exposure to maternal diabetes and childhood obesity. In: Freemark MS, (ed.) *Pediatric Obesity*. *Contemporary Endocrinology*. Humana Press, Cham2018. https://doi.org/10.1007/978-3-319-68192-4_13
9. Nommsen-Rivers LA. Does insulin explain the relation between maternal obesity and poor lactation outcomes? An overview of the literature. *Adv Nutr*. 2016;7(2):407-414.
10. Oza-Frank R, Chertok I, Bartley A. Differences in breast-feeding initiation and continuation by maternal diabetes status. *Public Health Nutr*. 2015;18(4):727-735.
11. World Health Organization (WHO). Infant and young child feeding. 2018; http://www.who.int/mediacentre/factsheets/fs342/en/.
12. Davis JN, Koleilat M, Shearrer GE, Whaley SE. Association of infant feeding and dietary intake on obesity prevalence in low-income toddlers. *Pediatr Obes*. 2014;22(4):1103-1111.

13. Davis JN, Weigensberg MJ, Shaibi GQ, et al. Influence of breastfeeding on obesity and type 2 diabetes risk factors in Latino youth with a family history of type 2 diabetes. *Diabetes Care*. 2007;30(4):784-789.
14. Yan J, Liu L, Zhu Y, Huang G, Wang PP. The association between breastfeeding and childhood obesity: a meta-analysis. *BMC Public Health*. 2014;14(1):1267.
15. American Academy of Pediatrics. Breastfeeding and the use of human milk. *Pediatrics*. 2012;129(3):e827-e841.
16. Centers for Disease Control and Prevention. Breastfeeding report card. 2016; https://www.cdc.gov/breastfeeding/pdf/2016breastfeedingreportcard.pdf. Accessed 04/21/2019.
17. Taveras EM, Gillman MW, Kleinman K, Rich-Edwards JW, Rifas-Shiman SL. Racial/ethnic differences in early-life risk factors for childhood obesity. *Pediatrics*. 2010;125(4):686-695.
18. Cantoral A, Tellez-Rojo MM, Ettinger AS, Hu H, Hernandez-Avila M, Peterson K. Early introduction and cumulative consumption of sugar-sweetened beverages during the pre-school period and risk of obesity at 8-14 years of age. *Pediatr Obes*. 2016;11(1):68-74.
19. Davis JN, Whaley SE, Goran MI. Effects of breastfeeding and low sugar-sweetened beverage intake on obesity prevalence in Hispanic toddlers. *Am J Clin Nutr*. 2012;95(1):3-8.
20. Moreno M. Early infant feeding and obesity risk. *JAMA Pediatr*. 2014;168(11):1084-1084.
21. Pan L, Li R, Park S, Galuska DA, Sherry B, Freedman DS. A longitudinal analysis of sugar-sweetened beverage intake in infancy and obesity at 6 years. *Pediatrics*. 2014;134(Suppl 1):S29-S35.
22. Davis JN, Koleilat M, Shearrer GE, Whaley SE. Association of infant feeding and dietary intake on obesity prevalence in low-income toddlers. *Obesity*. 2014;22(4):1103-1111.
23. The Los Angeles County Health Survey,. 2005. http://www.publichealth.lacounty.gov/ha/hasurveyintro.htm. Accessed October 2018.
24. Gill M, Koleilat M, Whaley SE. The impact of food insecurity on the home emotional environment among low-income mothers of young children. *Matern Child Health J*. 2018;22(8):1146-1153.
25. Liu J, Kuo T, Jiang L, Robles B, Whaley SE. Food and drink consumption among 1-5-year-old Los Angeles County children from households receiving dual SNAP and WIC v. only WIC benefits. *Public Health Nutr*. 2017;20(14):2478-2485.
26. 2014 survey of Los Angeles County WIC parents questionnaire 2014. http://lawicdata.org/wp-content/uploads/2014/05/2014-LA-WIC-Parents-Quex_eng.pdf. Accessed October 2018.
27. Shearrer GE, Whaley SE, Miller SJ, House BT, Held T, Davis JN. Association of gestational diabetes and breastfeeding on obesity prevalence in predominately hispanic low-income youth: gestational diabetes, breastfeeding and obesity. *Pediatr Obes*. 2014;10(3):165-171.
28. Koleilat M, Whaley SE. Reliability and validity of food frequency questions to assess beverage and food group intakes among low-income 2- to 4-year-old children. *J Acad Nutr Diet*. 2016;116(6):931-939.
29. Crespi CM, Alfonso VH, Whaley SE, Wang MC. Validity of child anthropometric measurements in the special supplemental nutrition program for women, infants, and children. *Pediatr Res*. 2012;71(3):286-292.
30. Assessing growth using the WHO growth charts. 2015. https://www.cdc.gov/nccdphp/dnpao/growthcharts/who/using/assessing_growth.htm. Accessed October 2018.
31. Centers for Disease Control and Prevention (CDC). Defining childhood obesity: BMI for children and teens. 2015; http://www.cdc.gov/obesity/childhood/defining.html. Accessed 04/21/2019.
32. Bider-Canfield Z, Martinez MP, Wang X, et al. Maternal obesity, gestational diabetes, breastfeeding and childhood overweight at age 2 years. *Pediatr Obes*. 2017;12(2):171-178.
33. Philipps LH, Santhakumaran S, Gale C, et al. The diabetic pregnancy and offspring BMI in childhood: a systematic review and meta-analysis. *Diabetologia*. 2011;54(8):1957-1966.
34. Regnault N, Gillman MW, Rifas-Shiman SL, Eggleston E, Oken E. Sex-specific associations of gestational glucose tolerance with childhood body composition. *Diabetes Care*. 2013;36(10):3045-3053.
35. Ouyang F, Parker MG, Luo Z-C, et al. Maternal BMI, gestational diabetes, and weight gain in relation to childhood obesity: the mediation effect of placental weight. *Obesity*. 2016;24(4):938-946.
36. Nehring I, Chmitorz A, Reulen H, von Kries R, Ensenauer R. Gestational diabetes predicts the risk of childhood overweight and abdominal circumference independent of maternal obesity. *Diabet Med*. 2013;30(12):1449-1456.
37. Dabelea D. The predisposition to obesity and diabetes in offspring of diabetic mothers. *Diabetes Care*. 2007;30(Suppl 2):S169-S174.
38. Gunderson EP, Greenspan LC, Faith MS, Hurstona SR, Quesenberrya CP, Jr. Breastfeeding and growth during infancy among offspring of mothers with gestational diabetesmellitus: A prospective cohort study. *Pediatr Obes*. 2018;13(8):492-504.
39. Aris IM, Soh SE, Tint MT, et al. Associations of infant milk feed type on early postnatal growth of offspring exposed and unexposed to gestational diabetes in utero. *Eur J Nutr*. 2017;56(1):55-64.
40. Rodekamp E, Harder T, Kohlhoff R, Franke K, Dudenhausen JW, Plagemann A. Long-term impact of breast-feeding on body weight and glucose tolerance in children of diabetic mothers: role of the late neonatal period and early infancy. *Diabetes Care*. 2005;28(6):1457-1462.
41. Logan KM, Emsley RJ, Jeffries S, et al. Development of early adiposity in infants of mothers with gestational diabetes mellitus. *Diabetes Care*. 2016;39(6):1045-1051.
42. Dieterich CM, Felice JP, O'Sullivan E, Rasmussen KM. Breastfeeding and health outcomes for the mother-infant dyad. *Pediatr Clin North Am*. 2013;60(1):31-48.
43. Smilowitz JT, Lebrilla CB, Mills DA, German JB, Freeman SL. Breast milk oligosaccharides: structure-function relationships in the neonate. *Annu Rev Nutr*. 2014;34(1):143-169.
44. Davis J, Ventura E, Weigensberg M, et al. The relation of sugar intake to beta-cell function in overweight Latino children. *Am J Clin Nutr*. 2005;82(5):1004-1010.
45. Davis JN, Alexander KE, Ventura EE, et al. Associations of dietary sugar and glycemic index with adiposity and insulin dynamics in overweight Latino youth. *Am J Clin Nutr*. 2007;86(5):1331-1338.
46. Lim S, Zoellner JM, Lee JM, et al. Obesity and sugar-sweetened beverages in African-American preschool children: a longitudinal study. *Obesity (Silver Spring)*. 2009;17(6):1262-1268.
47. Solomon CG, Willett WC, Rich-Edwards J, et al. Variability in diagnostic evaluation and criteria for gestational diabetes. *Diabetes Care*. 1996;19(1):12-16.

How to cite this article: Vandyousefi S, Whaley SE, Widen EM, et al. Association of breastfeeding and early exposure to sugar-sweetened beverages with obesity prevalence in offspring born to mothers with and without gestational diabetes mellitus. *Pediatric Obesity*. 2019;14:e12569. https://doi.org/10.1111/ijpo.12569