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Birth outcomes in relation to neighborhood food access and individual food insecurity during pregnancy in the Environmental Influences on Child Health Outcomes (ECHO)-wide cohort study

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Abbreviations: BW-for-GA, birth weight-for-gestational-age; CI, confidence interval; CRISYS-R, Crisis in Family Systems-Revised; ECHO, Environmental Influences on Child Health Outcomes; FARA, Food Access Research Atlas; GA, gestational age; LGA, large-for-gestational-age; LILA, low-income-low-food access; LILV, low-income-low-vehicle access; OR, odds ratio; SGA, small-for-gestational-age.

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ABSTRACT

Background: Limited access to healthy foods, resulting from residence in neighborhoods with low-food access or from household food insecurity, is a public health concern. Contributions of these measures during pregnancy to birth outcomes remain understudied.

Objectives: We examined associations between neighborhood food access and individual food insecurity during pregnancy with birth outcomes.

Methods: We used data from 53 cohorts participating in the nationwide Environmental Influences on Child Health Outcomes-Wide Cohort Study. Participant inclusion required a geocoded residential address or response to a food insecurity question during pregnancy and information on birth outcomes. Exposures include low-income-low-food-access (LILA, where the nearest supermarket is >0.5 miles for urban or >10 miles for rural areas) or low-income-low-vehicle-access (LILV, where few households have a vehicle and >0.5 miles from the nearest supermarket) neighborhoods and individual food insecurity. Mixed-effects models estimated associations with birth outcomes, adjusting for socioeconomic and pregnancy characteristics.

Results: Among 22,206 pregnant participants (mean age 30.4 y) with neighborhood food access data, 24.1% resided in LILA neighborhoods and 13.6% in LILV neighborhoods. Of 1630 pregnant participants with individual-level food insecurity data (mean age 29.7 y), 8.0% experienced food insecurity. Residence in LILA (compared with non-LILA) neighborhoods was associated with lower birth weight [β –44.3 g; 95% confidence interval (CI): –62.9, –25.6], lower birth weight-for-gestational-age z-score (–0.09 SD units; –0.12, –0.05), higher odds of small-for-gestational-age [odds ratio (OR) 1.15; 95% CI: 1.00, 1.33], and lower odds of large-for-gestational-age (0.85; 95% CI: 0.77, 0.94). Similar findings were observed for residence in LILV neighborhoods. No associations of individual food insecurity with birth outcomes were observed.

Conclusions: Residence in LILA or LILV neighborhoods during pregnancy is associated with adverse birth outcomes. These findings highlight the need for future studies examining whether investing in neighborhood resources to improve food access during pregnancy would promote equitable birth outcomes.

Keywords: neighborhood food access, food insecurity, birth weight, gestational age, health disparities, epidemiology

Introduction

Food insecurity, which is present when households have limited or uncertain access to adequate food because of limited money or other resources, is a persistent and intractable public health threat in the United States [1]. More than 10% of United States families in 2021 [2] and 7% of pregnant females in 2020 [3] experienced food insecurity. Although national food insecurity levels decreased from 20.6% in 2019 to 15.5% in 2021 among low-income adults, it rebounded to prepandemic levels (20.1%) in 2022 [4]. This issue is highly concerning given the strong links between food insecurity and a range of chronic diseases [1]. A 2021 meta-analysis of 35 published studies among nonpregnant adults found that food insecurity is significantly associated with a greater prevalence of obesity, diabetes, coronary artery disease, and chronic kidney disease [5], likely through psychological distress and behavioral adaptations that result from food insecurity (e.g., eating a diet rich in energy-dense but nutritionally poor foods) [6–8]. Similarly, food insecurity around the time of pregnancy has been shown to predict adverse maternal health outcomes, including poorer mental health, higher rates of obesity, excessive gestational weight gain, and gestational diabetes [9,10]. Less is known about the associations of prenatal food insecurity with offspring outcomes, an important topic for study given that pregnancy is a developmentally sensitive period that lays the foundation for long-term health [11].

Many previous studies of prenatal food insecurity and birth outcomes have been performed in international settings, especially in Africa [9], which may not be generalizable to the United States. In the Chemicals in Our Bodies-2 birth cohort in San Francisco, household food insecurity in the second trimester of pregnancy was associated with lower birth weight-for-gestational-age (BW-for-GA) z-scores, although the study was small ($n = 510$) and based in a single urban setting [12]. In the Pregnancy Risk Assessment Monitoring System study ($n = 50,915$ pregnancies from 15 states of United States), mothers living in food-insecure households had higher odds of delivering a low-birth weight infant [13]. In a study of 1,124,299 mother–newborn pairs in Ohio, residence in a neighborhood with low-food access at the time of birth was associated with a higher risk of preterm birth, although the analysis was limited to females who were underweight or normal weight, which is not likely representative given that overweight and obesity are common among those living in neighborhoods with low-food access [14]. An analysis of births in North Carolina in 2019 reported that county-level rate of food insecurity was the strongest predictor of infant mortality [15]. These studies, however, generally examined either household- or neighborhood-level metrics of food insecurity [12–14] but not both, an important aspect to consider given the inextricable relationship between the 2 variables [16], or did not control for individual-level socioeconomic factors [15].

To further advance knowledge of the relationship between prenatal food insecurity and birth outcomes, we analyzed data from racially, ethnically, and geographically diverse mother-child pairs enrolled in prospective birth cohorts participating in the nationwide Environmental Influences on Child Health Outcomes (ECHO)-Wide Cohort Study [17]. We aimed to determine the extent to which neighborhood-level food access and individual-level food insecurity during pregnancy contributed to adverse birth outcomes. We hypothesized that mothers residing in low-income-low-food access (LILA) neighborhoods and/or experiencing food insecurity during pregnancy would have higher rates of preterm, small-for-gestational-age (SGA), and large-for-gestational-age (LGA) births, independent of individual sociodemographic characteristics.

Methods

Study population

In its first funding cycle (2016–2023), ECHO comprised a consortium of 69 extant cohorts of children across the United States that had collected information on environmental exposures before age 5 y and assessed health outcomes throughout childhood [17–19]. Most ECHO cohorts started enrollment and recruitment in prenatal obstetric clinics or at birth [20]. Recruitment of new participants and follow-up of existing cohort participants throughout childhood is ongoing in cycle 2 (2023–2030). The investigators of the participating cohorts implemented the ECHO-wide cohort data collection protocol, which specifies the data elements for new or ongoing data collection as well as extant data to be uploaded to an ECHO-wide cohort data platform.

For this study, we used data from ECHO cycle 1 that were harmonized and shared on the ECHO data platform. We selected ECHO cohorts with data collected between 1 January 1997, and 1 March 2023, including participants who had high-quality data on geocoded residential addresses (i.e., either a point or specific street address) during pregnancy or who responded to a food insecurity question and had birth outcome data. Pregnant participants, or the child's parents or guardians, provided written informed consent for participation in the cohort of origin, and institutional review boards at each local study site or a central ECHO institutional review boards approved the protocol. This study followed the STROBE reporting guideline for cohort studies. The analysis plan for this study was documented in accordance with established protocols for the use of ECHO data [19].

Neighborhood-level food access exposure

Using ArcGIS geospatial software (Esri), the ECHO Data Analysis Center geocoded each participant's residential address obtained during pregnancy (year of residence 1997–2022) and assigned a census tract location to each address using 1990, 2000, 2010, or 2020 United States Census Tract Boundaries. The Data Analysis Center linked the resulting census tract location closest in time to the year of residence to census tract–level food access data from the US Food Access Research Atlas (FARA), which is the most comprehensive food environment classification in the United States [21]. Each census tract record in the dataset includes 16 variables that describe measures of food access in the form of urban/rural status, presence of group quarters, household income, distance to supermarket, and availability of a household vehicle. In accordance with FARA definitions, we identified LILA neighborhoods (yes or no) as low-income census tracts (where the federal poverty rate is ≥20% or median family income is ≤80% of the statewide median family income) with low-food access (where the nearest supermarket is >0.5 miles for urban areas or >10 miles for rural areas) [22]. We also considered other definitions of LILA neighborhoods contained in FARA, including low-income census tracts where the nearest supermarket is as follows: *1*) >1 mile for urban areas or >10 miles for rural areas or *2*) >1 mile for urban areas or >20 miles for rural areas [21]. Because vehicle access also is an important factor for determining food access, we additionally examined an indicator for low-income neighborhoods with low-income-low-vehicle access (LILV, yes or no) contained in FARA, defined as low-income census tracts where >100 housing units do not have a vehicle and are >0.5 miles from the nearest supermarket.

Individual-level food insecurity exposure

We assessed individual-level food insecurity during pregnancy using the Crisis in Family Systems-Revised (CRISYS-R) questionnaire, a validated measure of contemporary life stress. This questionnaire was originally developed in a population of adult primary caregivers of children residing in low-income urban areas in the United States [23] and has since been validated more broadly across the United States population [24,25]. The CRISYS-R includes 80 items from 12 domains encompassing financial, legal, relationship, medical issues pertaining to one's self, medical issues pertaining to others, community safety, safety in the home, housing, career, prejudice, authority, and acculturation [24]. During late pregnancy (mean 30.5 gestational wk), mothers responded to the following food insecurity question: "In the past year, did you go without food because you didn't have the money to pay for it?" We categorized respondents who answered "yes" to the question as food insecure, and those who responded "no" as food secure.

Birth outcomes

We obtained information on the following birth outcomes from hospital medical records or self-reports, according to the protocol for each cohort: gestational age (GA, in completed wk), preterm birth (GA <37 wk), and birth weight (BW, in g). We do not anticipate any bias from using self-reported birth outcomes, as previous studies [26,27] have shown high agreement for birth outcomes obtained by self-report compared with medical records. We derived sex-specific BW-for-GA z-scores, small-for-GA (SGA; BW-for-GA ≤10th percentile), and large-for-GA (LGA; BW-for-GA ≥90th percentile) using the 2017 United States' birth weight reference [28]. We chose this reference because it reflects nationally representative data on BW and obstetric estimates of GA in the United States.

Covariates

We obtained information on characteristics of mothers and children from maternal or caregiver reports (maternal age, education level during pregnancy, number of individuals in a household, insurance status, prenatal cigarette smoking or secondhand smoke exposure, and race and ethnicity) or medical records (prepregnancy BMI, parity, and child sex) and categorized them as follows: maternal age (in y) and education level during pregnancy (less than high school, high school diploma or equivalent, some college but no degree, or college degree and above), number of individuals in a household (1–2, 3–4, or 5+), insurance status (Medicaid, private, any other insurance, or no insurance), prepregnancy BMI (in kg/m^2), prenatal cigarette smoking or secondhand smoke exposure (yes or no), parity (0, 1-2, or 3+), and child's sex (male or female), race (American Indian or Alaskan Native, Asian, Black, Native Hawaiian or Pacific Islander, White, multiple races, or other race), Hispanic ethnicity, and year of residential address during pregnancy (1997–2007, 2008–2010, 2011–2019, or 2020–2022). Because of the small sample size, we combined children whose races were reported as American Indian or Alaskan Native, Native Hawaiian or Pacific Islander, multiple races, or other racial groups into a separate category of "Other." We used data on the urban/rural status of a census tract contained in FARA, whereby a census tract is considered urban if the tract is in an area with >2500 people and rural if the tract is in an area with ≤2500 people [29]. We selected these covariates based on previous publications examining associations between food insecurity and health outcomes [1,12–14].

Statistical analysis

In our main analyses, we used multilevel linear and logistic regression models to examine the associations of neighborhood-level

food access and individual-level food insecurity with continuous (GA, BW, and BW-for-GA *z*-scores) and dichotomous birth outcomes (preterm birth, SGA, and LGA), adjusting for the covariates described above except for race and ethnicity. We did this because we view race and ethnicity as societal constructs, rather than deterministic biological causes of disease risk [30]. Previous work [31] has suggested that membership in a particular racial group is a measure of structural racism and the resources (or lack thereof) attributed to this assigned membership may have a downstream impact on access to residential location, food, and health care resources likely associated with health outcomes. Hence, including race and ethnicity as covariates may result in an overadjustment of the associations of food access or food insecurity with birth outcomes.

We fit separate models for neighborhood-level food access and individual-level food insecurity with each birth outcome. In all models, we included random effects for a cohort to account for the clustering of children from the same cohort. In models for neighborhood-level food access, we additionally included random effects for census tract to account for the clustering of children residing within the same neighborhood.

We conducted several secondary analyses. We conducted a series of "leave-one-out" analyses, which repeated the main analysis excluding 1 cohort at a time to ensure that no single cohort substantially swayed the findings. In a separate model, we additionally adjusted for race and ethnicity to examine whether its inclusion would meaningfully change the effect estimates. We restricted our analyses for neighborhood-level food access to residential addresses obtained during or after 2014 to address potential misclassification, as we used FARA measures for the years 2015 and 2019. We explored effect modification by child's sex, race, birth year, and urban/rural status by adding multiplicative interaction terms with neighborhood-level food access. We also explored the extent to which associations for individual-level food insecurity may be modified by neighborhood-level food access, by including interaction terms between both variables among those with information on both.

We used multiple imputation by chained equations to impute missing covariate data (see Table 1). We generated 50 imputed data sets for all participants in the analytic sample. The imputation model included the exposure, outcome, and covariates under study. We combined the imputed data sets using the pool function in R software, version 4.2.2. In interpreting findings, we focused primarily on the direction, strength, and precision of the estimates and used 2-sided $\alpha = 0.05$ to assess statistical significance.

Results

Of 69 ECHO cohorts, we included 53 with 22,206 participants (mean age 30.4 y, SD 5.7) who had neighborhood-level food access data and information on birth outcomes (Supplemental Figures 1 and 2). Among pregnant individuals with neighborhood-level food access data, 3.1% identified as Asian, 13.7% Black, 11.1% other race, 12.4% unknown race, 59.5% White, 19.3% Hispanic, and 7.2% unknown ethnicity; and 52.6% had at least a college degree (Supplemental Table 1). In addition, 24.1% resided in LILA neighborhoods and 13.6% resided in LILV neighborhoods; the mean (SD) GA at birth was 38.3 (3.0) wk, and the BW-for-GA *z*-score was 0.04 (1.08) SD units. The prevalence of preterm birth was 11.3%, SGA 6.1%, and LGA 16.7% (Supplemental Table 2). Our sample also included 6 cohorts with 1630 participants (mean age 29.7 y, SD 5.8) who had individual food insecurity data (Supplemental Figures 1 and 2), of

whom 8.0% reported experiencing food insecurity and 98.5% ($n = 1606$) also had neighborhood-level food access data. Participants residing in LILA neighborhoods or experiencing food insecurity were more likely to identify as Black and were less likely to have a college degree or have private insurance (Table 1).

In models adjusted for year of residential address only (Figure 1, model 1), residence in LILA (compared with non-LILA) neighborhoods during pregnancy was associated with lower GA, BW, and BW-for-GA *z*-score. After additionally adjusting for socioeconomic and pregnancy characteristics (Figure 1, model 2), these associations were attenuated but remained statistically significant for BW [β –44.3 g; 95% confidence interval (CI): –62.9, –25.6] and BW-for-GA *z*-score (β –0.09 SD units; 95% CI: –0.12, –0.05) but not for GA. Residence in LILA (compared with non-LILA) neighborhoods during pregnancy was also significantly associated with higher odds of SGA [odds ratio (OR) 1.15; 95% CI: 1.00, 1.33] and lower odds of LGA (OR 0.85; 95% CI: 0.77, 0.94) (Figure 2). These associations remained largely similar for alternative definitions of LILA neighborhoods, albeit with wider 95% CI that crossed the null for SGA and LGA outcomes (Figures 1 and 2). Residence in LILV (compared with non-LILV) neighborhoods also was significantly associated with lower BW (β –45.6 g; 95% CI: –69.3, –24.4), lower BW-for-GA z-score (β –0.12 SD units; 95% CI: –0.16, –0.07), higher odds of SGA (OR 1.26; 95% CI: 1.07, 1.48), and lower odds of LGA (OR 0.80; 95% CI: 0.71, 0.92) in adjusted models (Supplemental Table 3).

In models adjusted for year of residential address only (Figure 3, model 1), point estimates showed that individual-level food insecurity during pregnancy was associated with lower BW (β –63.8 g; 95% CI: –166.3, 38.8) and GA (β –0.30 wk; 95% CI: –0.66, 0.05), lower odds of LGA (OR 0.65; 95% CI: 0.36, 1.15), and higher odds of preterm birth (OR 1.39; 95% CI: 0.80, 2.41). However, owing to the smaller sample size, these associations were imprecise with wide 95% CI that crossed the null. These associations did not change substantively after adjusting for socioeconomic characteristics (Figure 3, model 2 and Supplemental Table 3).

In the "leave-one-out" analyses, the association of residence in LILV neighborhoods with lower BW-for-GA and lower odds of LGA was not substantially different from our main analyses (Supplemental Figures 3 and 4). However, the associations of residence in LILA or LILV neighborhoods with adverse birth outcomes (i.e., lower BW-for-GA and higher odds of SGA) were substantially attenuated to nonsignificance after additionally adjusting for race and ethnicity (Figures 1 and 2, model 3), except for the association of residence in LILV neighborhoods with lower BW-for-GA *z*-score (β –0.04 SD units; 95% CI: –0.09, 0.00). The association between individual-level food insecurity during pregnancy and birth outcomes did not change after additional adjustment for race and ethnicity (Figure 3, model 3). When restricting analyses to residential addresses obtained during or after 2014, the associations of residence in LILA or LILV neighborhoods with adverse birth outcomes were similar to our main analyses, albeit with wider 95% CI, which might be attributed to the smaller sample size (Supplemental Table 4). No clear evidence of effect modification by child sex, race, urban/rural status, and year of residential address was present (Supplemental Figures 5–8). We did observe that residence in LILV neighborhoods during pregnancy was significantly associated with lower odds of LGA (OR 0.75; 95% CI: 0.59, 0.96) among Black mothers only. The association between individual-level food insecurity during pregnancy and birth outcomes also did not appear to be modified by neighborhood-level food access (Supplemental Figure 9).

TABLE 1

Participant characteristics according to neighborhood food access (non-LILA vs. LILA) and individual food insecurity status (no vs. yes)

	Neighborhood-level food access (N = 22,206)		Individual-level food insecurity (N = 1630)	
	Non-LILA[1] (N = 19,196)	LILA[1] (N = 3010)	No[1] (N = 1501)	Yes[1] (N = 129)
Child sex				
Female	48.4%	48.3%	48.4%	51.6%
Male	51.6%	52.7%	51.6%	48.4%
Ethnicity				
Hispanic	19.6%	17.2%	35.2%	45.0%
Non-Hispanic	72.8%	78.1%	54.3%	33.3%
Unknown	7.6%	4.7%	10.5%	21.7%
Race				
Asian	3.4%	1.4%	2.1%	1.6%
Black	9.6%	40.2%	22.6%	25.6%
Other (American Indian or Alaskan Native,	10.8%	13.1%	11.6%	9.3%
Native Hawaiian or Pacific Islander, multiple races, or other race)				
Unknown	13.2%	7.5%	26.7%	38.8%
White	62.9%	37.8%	37.0%	24.8%
Education level during pregnancy				
Less than high school	7.5%	14.3%	17.1%	35.7%
High school degree or equivalent	14.8%	31.5%	21.2%	25.8%
Some college, no degree	21.6%	26.7%	27.1%	26.6%
College degree and above	56.1%	27.5%	34.6%	11.9%
Prenatal smoking or secondhand smoke exposure				
No	74.9%	58.7%	74.1%	70.4%
Yes	25.1%	41.3%	25.9%	29.6%
Insurance status during pregnancy				
Medicaid	10.5%	21.9%	31.1%	44.8%
Private	87.5%	76.2%	63.6%	50.7%
Any other insurance	1.3%	0.6%	3.9%	3.4%
No insurance	0.6%	1.3%	1.3%	1.1%
Year of residential address				
1997–2007	12.2%	20.2%	26.1%	27.1%
2008–2010	11.4%	15.2%	1.0%	1.6%
2011–2019	64.7%	57.7%	62.8%	53.5%
2020–2022	11.7%	6.8%	10.2%	17.8%
Urban/rural status				
Rural	21.0%	6.1%	8.1%	5.7%
Urban	79.0%	93.9%	91.9%	94.3%
Parity				
0	76.4%	64.6%	68.8%	68.6%
1–2	19.5%	27.1%	24.4%	23.6%
3+	4.2%	8.2%	6.8%	7.8%
Number of individuals in household				
1–2	65.5%	61.0%	54.3%	50.1%
3–4	27.0%	24.3%	31.8%	35.2%
5+	7.5%	14.7%	13.8%	14.7%
Maternal age (y)	30.8 (5.6)	27.6 (5.7)	29.8 (5.8)	28.3 (5.6)
Prepregnancy BMI (kg/m^2)	26.8 (6.8)	29.1 (8.4)	28.1 (7.4)	28.8 (8.1)

Abbreviation: LILA, low-income-low-food access.

[1] % calculated using imputed data.

Discussion

In this nationwide study, we observed that residence in LILA or LILV neighborhoods during pregnancy was associated with adverse birth outcomes of lower BW and BW-for-GA z-score and higher odds of SGA. These associations were independent of socioeconomic and pregnancy characteristics previously associated with adverse birth outcomes. Additional adjustment for race and ethnicity meaningfully attenuated these associations to nonsignificance. To the extent that the self-reported social constructs of race and ethnicity reflect proxy measures of structural racism [30–33], this finding suggests that structural racism is related to the inequitable distribution of individuals in LILA or LILV neighborhoods because of the influence of

historical and contemporary policies and practices such as race-based residential segregation [34]. Moreover, structural racism may be related to differential exposure to factors that would negatively affect birth outcomes, such as access to health care services and resources [35], environmental chemicals [36], violence and crime [37], or other features. In fact, previous studies [38,39] have demonstrated how inclusion of race and ethnicity as a covariate eliminated the predictive value of objectively assessed neighborhood quality and violent crime on child mental health outcomes, potentially misleading researchers to believe that the neighborhood does not matter for health outcomes. Altogether, these findings exemplify how adjustment for race and ethnicity may be inappropriate [40,41] and could impede efforts that seek to better
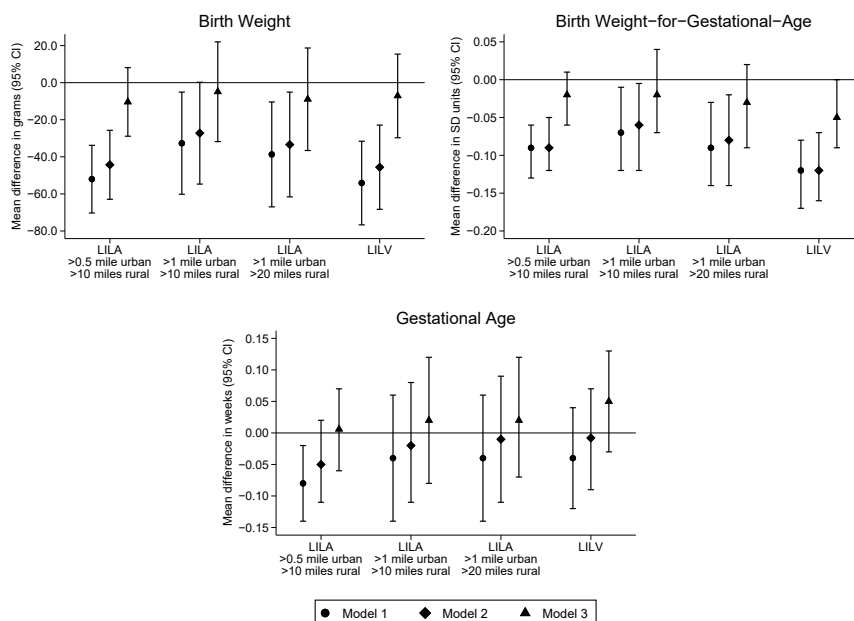
FIGURE 1. Associations of neighborhood-level food access with birth weight, birth weight-for-gestational-age, and gestational age. Model 1: adjusted for year of residential address during pregnancy. Model 2: model 1 + age, educational level during pregnancy, number of individuals in a household, insurance status, prepregnancy BMI, prenatal cigarette smoking or secondhand smoke exposure, parity, and child sex. Model 3: model 2 + race and ethnicity. LILA, low-income-low-food access; LILV, low-income-low-vehicle access.

understand differences in birth outcomes according to neighborhood food access during pregnancy.

Our results for neighborhood food access during pregnancy and birth outcomes generally align with previous studies from both developed and developing countries, although specific neighborhood food access metrics have varied. In the United States, 2 studies in South Carolina [42] and New York [43] showed that residence in neighborhoods with greater access to unhealthy foods was associated with lower
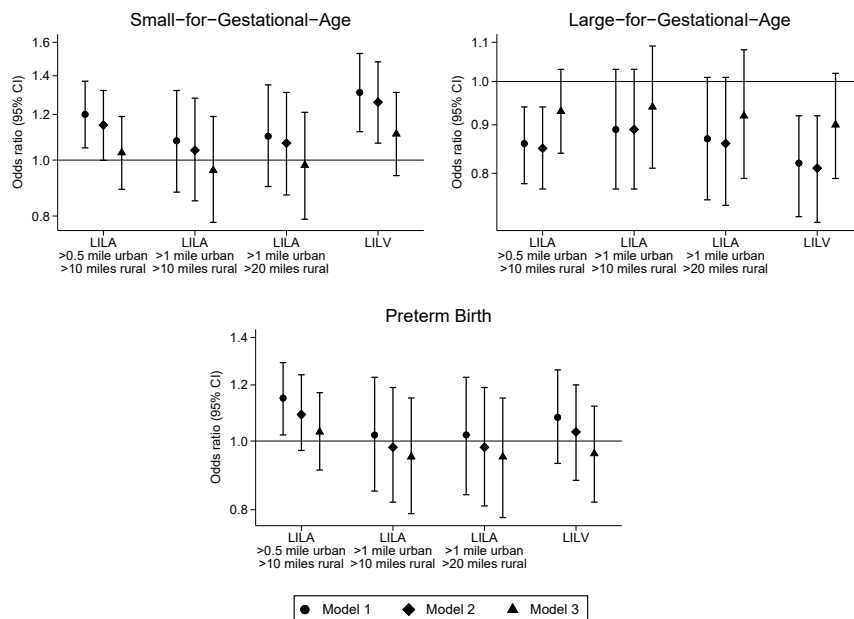
FIGURE 2. Association of neighborhood-level food access with small-for-gestational-age, large-for-gestational-age, and preterm birth. Model 1: adjusted for year of residential address during pregnancy. Model 2: model 1 + age, educational level during pregnancy, number of individuals in a household, insurance status, prepregnancy BMI, prenatal cigarette smoking or secondhand smoke exposure, parity, and child sex. Model 3: model 2 + race and ethnicity. LILA, low-income-low-food access; LILV, low-income-low-vehicle access.
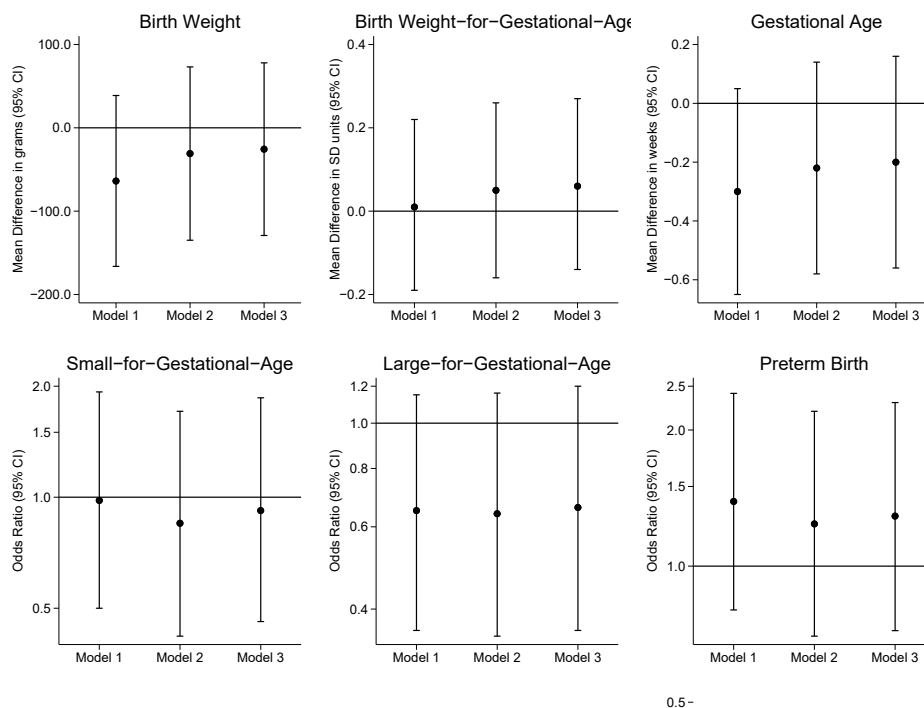
FIGURE 3. Association of individual-level food insecurity with birth outcomes. Model 1: adjusted for year of residential address during pregnancy. Model 2: model 1 + age, educational level during pregnancy, number of individuals in a household, insurance status, prepregnancy BMI, prenatal cigarette smoking or secondhand smoke exposure, parity, and child sex. Model 3: model 2 + race and ethnicity.

BW and GA and higher risk of SGA. Lane et al. [44] reported that in New York, females who resided in neighborhoods without a supermarket within 1.5 miles were 3 times more likely to have low-BW newborns. In Canada, Savard et al. [45] reported that the odds of SGA birth were higher in neighborhoods with a high proportion of residents who were experiencing food insecurity. In Brazil, females living in municipalities with limited access to healthy foods had a higher risk of having SGA or low-BW newborns [46]. These studies and others, however, were largely cross-sectional in study design [42, 43,45,46], limited by smaller sample sizes [12,44], or lacked geographic diversity [12,14,15,42–44] because they were conducted only within a single state in the United States. Our study directly addresses these key research gaps by assembling a large and geographically diverse cohort of participants that is more generalizable to the United States population (see Supplemental Figure 1). Taken together, our findings contribute substantially to the small but growing body of evidence linking neighborhood food environment in early life with birth outcomes.

We did not observe significant associations of individual-level food insecurity with birth outcomes, although effect estimates were in the hypothesized directions for GA and BW. This observation could likely be because the sample size for the analysis of individual-level food insecurity was smaller, and thus, statistical power and precision may have been limited. Moreover, the lack of association between individual-level food insecurity and birth outcomes might stem from the fact that we ascertained food insecurity from only a single question in the CRISYS-R questionnaire. This question likely excludes individuals with less severe forms of food insecurity and may be less sensitive than the 18-item United States Household Food Security Survey [47], which assesses food insecurity more comprehensively.

Several potential mechanisms could explain our observations. First, the neighborhood food environment (i.e., availability and/or accessibility of healthy and unhealthy foods) plays an important role in influencing the dietary quality of pregnant females [48], which may subsequently affect birth outcomes. Notably, a previous study in ECHO reported a higher risk of inadequate micronutrient intake during pregnancy among participants of non-White race or Hispanic ethnicity or those with less than a high school education [49], a demographic previously shown to more likely reside in neighborhoods with unhealthy food environments [43]. Substantive evidence has shown that fetal growth is vulnerable to dietary deficiencies of nutrients during pregnancy [50]. Second, neighborhoods with low access to supermarkets, supercenters, or large grocery stores might in turn have greater access to smaller convenience stores [51], which implies greater access to and consumption of other harmful substances that are known to negatively affect fetal growth, including highly processed foods that contain endocrine disrupting chemicals, alcohol, and tobacco [52–54]. Finally, low-income neighborhoods with low-food access could simply reflect disadvantaged neighborhood environments with higher rates of other social (e.g., poverty and violent crime) and environmental (e.g., toxic chemicals and traffic-related air pollutants) stressors that can affect pregnancy health and wellbeing. Hence, beyond affecting dietary quality of pregnant females, it is possible that residence in LILA or LILV neighborhoods may negatively affect birth outcomes through increased psychological stress [55], increased exposure to environmental pollutants [56], or other factors. Although this is beyond the scope of the current study, future studies in ECHO or other settings could be done to explore these potential mechanisms.

Strengths of our study include the large sample size and the wide range of covariates. We used neighborhood food access indices that have been validated for a wide range of health outcomes [22,57,58]. We were also able to control for individual-level factors (e.g., mother's education level and insurance status) that may likely influence residential selection. This study, however, has several limitations. First, we

used residential census tracts as a marker of exposure, which may not capture the relevant areas where pregnant females spend most of their time. Second, certain covariates (e.g., education level during pregnancy) had a substantial percentage of missing data, which may have impacted our findings. However, we used flexible multiple imputation techniques that reduce bias and the likelihood of spurious results. Third, despite our efforts to adjust for multiple covariates, we cannot exclude the possibility that residual confounding by unmeasured risk factors of birth outcomes could explain our observations. Fourth, we used FARA information for 2015 and 2019 that may have been misclassified for residential addresses during the 1990s or 2000s. However, results for LILA or LILV restricted to residential addresses obtained during or after the year 2014 were similar to our main findings. Fifth, our findings may not be generalizable to other ethnic groups and populations from different countries, because all participants in this study were from the United States. Finally, this study did not consider how residential mobility during pregnancy may influence changes in neighborhood food access over time and whether such changes may alter birth outcomes. Although this question is beyond the scope of the current study, follow-up studies in ECHO investigating these associations will be considered to evaluate its impact on birth outcomes.

In conclusion, the results of this cohort study of >20,000 pregnancies enrolled in >50 cohorts across the United States suggest that residence in low-income neighborhoods with low-food access or low vehicle access during pregnancy is associated with adverse birth outcomes. These findings suggest that developing strategies to improve healthful food access during pregnancy, a sensitive period for maternal and fetal health may promote equitable birth outcomes in the United States. A variety of strategies might be needed, such as improving neighborhood food access, policies directed at those living in low-access neighborhoods to improve food affordability, or efforts to directly provide healthful food during pregnancy. Given the long-term effects of adverse birth outcomes on later cardiovascular disease risk in adolescence [59] and adulthood [60,61], additional research is warranted to evaluate interventions and policies that would be most effective in improving birth outcomes and promoting child health.

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Author contributions

The authors' responsibilities were as follows – IMA, P-IDL, EO: developed the concept and design; IMA, P-IDL: acquired or analyzed the data; IMA, EO: drafted the manuscript and had primary responsibility for the final content; AJW, DD, BML, RJW, MRK, JMK, ALD, CLMJ, CACJ, JMG, RJS, RSS, CTM, AEH, TMO, LAM, LEM, ZN, AF, YZ, RFC, EWK, NRB, RHNN, KNC, ESB, KL, LMS-T, LT, JMB, CVB, MAP, BC, NA-O, MRK, TJT: contributed to the interpretation of the findings; and all authors: read and approved the final manuscript.

Conflict of interest

The authors report no conflicts of interest.

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Data availability

Data described in the manuscript, code book, and analytic code will be made available upon request pending approval.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajcnut.2024.02.022.

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