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Disparities in Risks of Inadequate and Excessive Intake of Micronutrients during Pregnancy

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ABSTRACT

Background: Inadequate or excessive intake of micronutrients in pregnancy has potential to negatively impact maternal/offspring health outcomes.

Objective: The aim was to compare risks of inadequate or excessive micronutrient intake in diverse females with singleton pregnancies by strata of maternal age, race/ethnicity, education, and prepregnancy BMI.

Methods: Fifteen observational cohorts in the US Environmental influences on Child Health Outcomes (ECHO) Consortium assessed participant dietary intake with 24-h dietary recalls (n = 1910) or food-frequency questionnaires (n = 7891) from 1999–2019. We compared the distributions of usual intake of 19 micronutrients from food alone (15 cohorts; n = 9801) and food plus dietary supplements (10 cohorts with supplement data; n = 7082) to estimate the proportion with usual daily intakes below their age-specific daily Estimated Average Requirement (EAR), above their Adequate Intake (AI), and above their Tolerable Upper Intake Level (UL), overall and within sociodemographic and anthropometric subgroups.

Results: Risk of inadequate intake from food alone ranged from 0% to 87%, depending on the micronutrient and assessment methodology. When dietary supplements were included, some women were below the EAR for vitamin D (20–38%), vitamin E (17–22%), and magnesium (39–41%); some women were above the AI for vitamin K (63–75%), choline (7%), and potassium (37–53%); and some were above the UL for folic acid (32–51%), iron (39–40%), and zinc (19–20%). Highest risks for inadequate intakes were observed among participants with age 14–18 y (6 nutrients), non-White race or Hispanic ethnicity (10 nutrients), less than a high school education (9 nutrients), or obesity (9 nutrients).

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Conclusions: Improved diet quality is needed for most pregnant females. Even with dietary supplement use, >20% of participants were at risk of inadequate intake of ≥1 micronutrients, especially in some population subgroups. Pregnancy may be a window of opportunity to address disparities in micronutrient intake that could contribute to intergenerational health inequalities. *J Nutr* 2021;151:3555–3569.

Keywords: pregnancy, micronutrients, diet, dietary supplements, vitamins, minerals, Dietary Reference Intakes

Introduction

Prenatal nutrition has immediate and long-term implications for offspring health (1). Prenatal deficiencies have been associated with offspring neural tube defects (folic acid) (2), alterations in cardiovascular structure (vitamin A) (3), and impaired neurocognitive development (iron, zinc, choline) (4, 5), whereas excessive intake of certain micronutrients, such as the methyl donors folate and vitamin B-12, may increase chronic disease risk in offspring through alterations in DNA methylation (6). Micronutrients may also modify the effect of adverse environmental exposures during pregnancy (7, 8), highlighting the importance of optimizing micronutrient intake in pregnancy for offspring health outcomes.

While micronutrient deficiency is generally a concern in lower-income countries, a 2013 meta-analysis of food intake only reported that many pregnant women in high-income countries also have inadequate micronutrient intake, particularly for folate, vitamin D, and iron (9). More recently, a nationally representative sample of the US pregnant women populations estimated that at least 1 in 3 pregnant women aged 20–40 y were at risk of inadequate intake of vitamin D, vitamin E, and magnesium, while 1 in 10 were at risk of inadequate intake of vitamin A, vitamin B-6, vitamin C, calcium, and zinc, even with dietary supplement use (10). Risk of excessive intake was also notable, with nearly one-third of pregnant women exceeding the Tolerable Upper Intake Level (UL) for folate and iron, and mean intakes of vitamins B-6 and B-12 at 5–10 times the Estimated Average Requirement (EAR) (10). Disparities in risks of inadequate or excessive intake according to race/ethnicity or educational attainment have been reported in a small study (11), suggesting that strategies to optimize micronutrient intake may need to be tailored to specific groups. However, data from large, diverse populations are needed to identify the specific subgroups at risk of inadequate and excessive micronutrient intake in advance of developing targeted approaches to optimize intake.

Here, we explored disparities in risks of inadequate or excessive prenatal micronutrient intakes in a large, diverse sample of pregnant women participating in a national consortium of pregnancy and pediatric cohorts. We compared their intake to the DRIs defined by the Food and Nutrition Board of the Institute of Medicine, which reflect the amount that should be consumed daily to meet the physiological requirements for each sex and life stage that promote health and avoid disease (12). We report risks of inadequate or excessive intake relative to pregnancy-specific DRIs, overall and within maternal age, race/ethnicity, education, and prepregnancy BMI categories. Our goal was to identify patterns of prenatal micronutrient intake that may be contributing to disparities in maternal/child health outcomes (13–16).

Methods

The Environmental influences on Child Health Outcomes (ECHO) is a national consortium of pediatric, longitudinal, observational cohorts established in 2016 by the NIH to understand the effects of early-life exposures on child health and development. Data-collection methods are summarized in **Table 1** for the 15 cohorts across 14 states that contributed data from 9801 singleton pregnancies to this analysis. Fourteen cohorts enrolled pregnant females and collected data in pregnancy ($n = 9293$), and 1 cohort enrolled mothers of children aged 2–5 y, with retrospective assessment of early pregnancy characteristics and dietary intake ($n = 508$). All cohorts collected sociodemographic and weight-related data via self-report and/or medical records, including age (14–18, 19–30, 31–50 y), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic any race, non-Hispanic other race), education (<high school degree, high school degree, some college or 2-y degree, ≥4-year degree), and prepregnancy BMI (in kg/m^2; underweight, <18.5; normal weight, 18.5–24.9; overweight, 25–29.9; obese, ≥30). All cohort-specific protocols were approved by the institutional review boards with jurisdiction in each study location, and all participants provided informed consent. De-identified, individual-level datasets of diet and characteristics were transferred to the University of Colorado under data use agreements.

Dietary data

Five cohorts assessed dietary intake with interviewer- or self-administered 24-h recalls ($n = 1910$ participants) (17, 18). Two of these

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Supplemental Figures 1–3 and Supplemental Tables 1–10 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents available on https: //academic.oup.com/jn.
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Abbreviations used: AI, Adequate Intake; CMH, Cochran-Mantel-Haenszel; EAR, Estimated Average Requirement; ECHO, Environmental influences on Child Health Outcomes; FFQ, food-frequency questionnaire; UL, Tolerable Upper Intake Level.

TABLE 1 Characteristics of ECHO cohorts that assessed prenatal dietary intake[1]

Cohort name, recruitment area (years of data collection)	Specific method or questionnaire (reference)	Gestational range of administration (time frame of recall)	Nutrient database	Supplement database (if applicable)	*n*
24-Hour recalls					
Safe Passage, Sioux Falls and Rapid City, SD (2007–2015)	Interviewer-administered USDA Automated Multiple Pass Method, with supplement module (17)	20–40 wk gestation (prior 24 h)	University of Minnesota's Nutrition Data System for Research	University of Minnesota's Nutrition Data System for Research	64
Healthy Start, Aurora, CO (2009–2014)	Automated Self-Administered 24-h recall (18) and supplement form querying brand, type, dose	6–40 wk gestation (prior 24 h)	Food and Nutrient Database for Dietary Studies	Product labels, Dietary Supplement Label Database	1363
ARCH, Lansing, Michigan (2015–2017)	Unstructured 24-h recall	15–35 wk gestation (prior 24 h)	Food and Nutrient Database for Dietary Studies	—	50
MADRES, Los Angeles, CA (2015–2019)	Automated Self-Administered 24-h recall (18)	28–38 wk gestation (prior 24 h)	Food and Nutrient Database for Dietary Studies	—	178
Rochester, Rochester, NY (2015–2019)	Interviewer-administered USDA Automated Multiple Pass Method (17)	16–39 wk gestation (prior 24 h)	University of Minnesota's Nutrition Data System for Research	—	255
Food-frequency questionnaires					
Project Viva,[2] Boston, MA (1999–2003)	Self-administered Harvard FFQ (modified for use in pregnancy) (19) and supplement form querying brand, type, dose	5–40 wk gestation (prior 3 mo)	Harvard nutrient composition database	Harvard nutrient composition database	1872
CHARGE, Davis/Sacramento, CA, and surrounding area (2003–2009)	Self-administered Modified Block-Muldoon FFQ for Pregnancy (with added questions for fish intake/omega-3 fatty acids) (20) and supplement form querying brand, type, dose	Offspring age 2–5 y (reflecting entire prenatal period)	Nutrition Quest nutrient composition database	Product labels, University of Minnesota's Nutrition Data System for Research	508
CANDLE, Shelby County, TN (2006–2011)	Block FFQ 2005 with supplement questions (21)	15–35 wk gestation (prior 3 mo)	Nutrition Quest nutrient composition database	Nutrition Quest nutrient composition database	1322
MARBLES,[2] Davis/Sacramento, CA, and surrounding area (2006–2020)	Block FFQ 2005 (21) with supplement form querying brand, type, dose	10–40 wk gestation (1–20 wk and 20–40 wk gestation)	Nutrition Quest nutrient composition database	Product labels, University of Minnesota's Nutrition Data System for Research	221
New Hampshire Birth Cohort Study, State of New Hampshire (2009–2018)	Harvard FFQ (22)	20–40 wk gestation (since becoming pregnant)	Harvard nutrient composition database	—	1322
EARLI,[2] Philadelphia, PA; Baltimore, MD; San Francisco Bay Area, CA; Sacramento, CA (2011–2017)	Modified National Cancer Institute Dietary History Questionnaire (23) with supplement form querying brand, type, dose	16–39 wk gestation (prior 3 mo)	National Cancer Institute's Diet History Questionnaire nutrient database	Product labels, University of Minnesota's Nutrition Data System for Research	195
PRISM, Boston, MA, and New York City, NY (2011–2017)	Interviewer-administered modified Block-Bodnar FFQ with supplement questions (24)	8–40 wk gestation (prior 3 mo)	Nutrition Quest nutrient composition database	Product labels, Dietary Supplement Label Database, Dietary Supplement Ingredient Database	567
PETALS, Greater San Francisco Bay Area, CA (2013–2018)	Self-administered Block FFQ (21)	10–13 wk gestation (prior 3 mo)	Food and Nutrient Database for Dietary Studies	—	914

(*Continued*)

TABLE 1 (*Continued*)

Cohort name, recruitment area (years of data collection)	Specific method or questionnaire (reference)	Gestational range of administration (time frame of recall)	Nutrient database	Supplement database (if applicable)	*n*
Atlanta ECHO Cohort of Emory University, Atlanta, GA (2014–2019)	Block-Bodnar FFQ with supplement questions (24)	8–14 and 24–30 wk gestation[2] (prior 4 mo)	Food and Nutrient Database for Dietary Studies	Nutrition Quest nutrient composition database	310
NYU CHES, New York City, NY (2016–2019)	National Cancer Institute Dietary History Questionnaire-2 with supplement questions (25)	18–40 wk gestation (prior 12 mo)	National Cancer Institute's Diet History Questionnaire nutrient database	National Cancer Institute's Diet History Questionnaire nutrient database	660

[1]ARCH, Archive for Research in Child Health; CANDLE, Conditions Affecting Neurocognitive Development and Early Learning; CHARGE, CHildhood Autism Risk from Genetics and the Environment Study; EARLI, Early Autism Risk Longitudinal Investigation; ECHO, Environmental influences on Child Health Outcomes; FFQ, food-frequency questionnaire; MADRES, Maternal And Developmental Risks from Environmental and Social Stressors; MARBLES, Markers of Autism Risk in Babies: Learning Early Signs; MARCH, Michigan Archive for Research in Child Health; NYU CHES, New York University Children's Health and Environment Study; PETALS, Pregnancy Environment and Lifestyle Study; PRISM, Pediatric Research using Integrated Sensor Monitoring Systems.
[2]Two or more FFQs were administered during pregnancy and were averaged for analysis.

cohorts ($n = 1427$ participants) also assessed dietary supplement use by querying brand name, type, and dose and used to obtain exact estimates of micronutrient content from nutrient databases and/or manufacturer labels. Ten cohorts assessed dietary intake with various food-frequency questionnaires (FFQs; $n = 7891$ participants) (19–25), including the cohort that retrospectively assessed prenatal diet at offspring age 2–5 y ($n = 508$). Of these, 8 assessed dietary supplement use ($n = 5655$ participants), with 4 querying brand name, type, and dose to obtain exact contents. The other 4 cohorts used the supplement questions built into the Block or National Cancer Institute FFQs, which queried type of supplement (prenatal, multivitamin, other single nutrients) and applied mean values of nutrient contents to intake estimates. All cohorts processed their raw dietary data locally using appropriate databases for food and dietary supplement nutritional content at the time of data collection (Table 1). Separately for food and supplements, they provided data on daily intake of 19 micronutrients for which pregnancy-specific DRIs for daily intake exist (12): vitamins A, C, D, E, and K; thiamin; riboflavin; niacin; folate/folic acid; vitamin B-12; choline; calcium; copper; iron; magnesium; phosphorus; zinc; and potassium. We did not analyze selenium because the exact content in food is largely influenced by regional differences in soil composition (26).

Dietary Reference Intakes

We aimed to understand risk of inadequate and excessive intakes by comparing usual daily intakes to the EAR, Adequate Intake (AI), and UL specified by the DRIs (12). The EAR reflects the average daily nutrient intake level estimated to meet the requirements of half of the healthy individuals in a group, such that the prevalence of intakes below the EAR reflects the prevalence of inadequacy. For nutrients without an EAR (vitamin K, choline, potassium), an AI level is provided. The AI is believed to cover the needs of all healthy individuals, such that when the mean intake of a group is at or above the AI, a low prevalence of inadequacy is assumed. The UL is the highest daily nutrient intake likely to pose no risk of adverse health effects to most individuals. While exact nutrient requirements for any specific individual cannot be defined, risk of inadequacy for a population can be estimated with the cut-point method, wherein the prevalence of intakes below the EAR reflects the percentage of the population at risk of inadequate intake (27). For nutrients with an AI, we used the cut-point method to determine the percentage of the population above the AI, for whom risk of inadequacy is assumed to be low. Similarly, the percentage of the population above the UL reflects the proportion at risk of excessive intake. We note that the cut-point method assumes that nutrient requirements are normally distributed within a population, which is not the case for menstruating females whose iron requirement varies according to blood loss during menses (28, 29). However, we elected to use the cut-point method for iron given that all participants were pregnant and not menstruating. For age-stratified analyses, we used the DRIs specified for each age category (14–18, 19–30, 31–50 y) (12). For analyses stratified by the other characteristics (race/ethnicity, education, prepregnancy BMI), we used the DRIs for pregnant females aged 19–30 years because *1*) only 4% of participants were 14–18 y and *2*) DRIs for pregnant females aged 31–50 y were the same for all nutrients except for magnesium (EAR = 290 vs. 300 mg, respectively).

Estimating usual intake distributions

24-Hour recall data.

Cohorts that assessed intake with 24-h recalls provided micronutrient data for ≥1 repeated observation(s) (days) for each participant (70% of participants had ≥2 recalls). We used an extension of the National Cancer Institute's measurement error model to estimate the distribution of usual intakes of micronutrients from food alone for intake assessed with recalls (30). This model produces population point estimates by partitioning out the intraindividual (day-to-day) component of variation when estimating the distributions of intakes. First, we transformed the distributions with the Box-Cox parameter that optimized the normality of the residuals on a per-micronutrient basis. The resulting transformed data produced errors with a distribution more closely approximating normality. We fit a general linear mixed

model to the transformed data, extending the measurement error model method as described by Tooze and colleagues (31) to include 2 random effects and thereby account for the 2-level nested clustering. The first random effect accounted for correlation of the repeated recalls within participants. The second random effect accounted for the clustering of participants within ECHO cohorts. The overall variance pattern was thus Kronecker product compound symmetric. The repeated recalls within each participant were assumed to have equal correlation and equal variance. Participants were assumed to be exchangeable within cohort, and thus have equal variance and equal correlation within cohorts. We used the model-provided estimates of the quantiles of the distribution of usual daily intake to calculate the proportion of participants with intakes below the EAR, above the AI, and above the UL.

We also estimated the usual daily intake of micronutrients from food and dietary supplements combined. One cohort with both food and supplement data assessed dietary supplement use as part of the recall but calculated micronutrient intake from each source separately. To estimate usual intake from both sources, we summed the daily intakes from food and supplements. The second cohort with food and supplement data assessed dietary supplement use outside of the recalls with a separate questionnaire up to 3 times in pregnancy. To estimate usual daily intake from both sources in this cohort, we matched recalls with the appropriate questionnaire based on date of administration. Participants who reported daily dietary supplement use at the time of the recall were assumed to have taken the supplement on the day of the recall; thus, we added the dietary supplement intake to the recall (food-based) intake. For participants who reported less than daily dietary supplement use at the time of the recall, we computed the probability that they took the supplement on the day of the recall based on their reported frequency of use (e.g., every other day). We used a Bernoulli distribution (32) to simulate the occurrence of intake on each recall day. If we sampled a success (i.e., result indicating the supplement was taken on the day of the recall), we added the dietary supplement intake to the recall (food-based) intake; otherwise, the dietary supplement intake was not added. We then applied the measurement error model described above to recall data from both cohorts, again obtaining estimates of inadequate or excessive intake from food and supplements, both overall and stratified by sociodemographic and weight-related characteristics.

FFQ data

Cohorts that assessed intake with FFQ data provided micronutrient data for ≥1 administration(s) (22% of participants had ≥2 FFQs). For cohorts (n = 3) that administered the FFQ and/or collected dietary supplement information multiple times in pregnancy, data were averaged for analysis. By design, FFQs provide estimates of usual daily intake over time and do not require further modeling to account for day-to-day variability. As with recall data, we first transformed the distributions with the Box-Cox parameter that optimized the normality of the residuals on a per-micronutrient basis. The resulting transformed data produced errors with a distribution more closely approximating normality. We then fit a general linear mixed model to the transformed data that included a random effect to account for the clustering of participants within ECHO cohorts. Again, participants were assumed to be exchangeable within cohort, and thus have equal variance and equal correlation within cohorts. We used the model-provided estimates of the quantiles of the distribution of usual daily intake to calculate the proportion of participants with intakes below the EAR, above the AI, and above the UL, both overall and stratified by the sociodemographic and weight-related characteristics. For cohorts with diet and supplement data from FFQs, we added the daily intakes to calculate the proportion with inadequate or excessive intake from food and dietary supplements, again overall and within designated strata.

Harmonization of recall and FFQ data

As distributions of intake derived from recall methods are known to vary from FFQ methods (33), combining them can produce incorrect estimates. To evaluate the validity of combining data across cohorts that administered recalls compared with FFQs, we examined heterogeneity with a hypothesis-testing approach by assessing the difference in mean intake for each micronutrient between methodologies using a Satterthwaite t test at a Bonferroni-corrected α level of 0.05/19 = 0.0026. For all micronutrients, differences in mean daily intakes were statistically significant different between recall and FFQ data. Therefore, we did not combine data across dietary assessment methodology but present results separately.

Statistical analyses

We used Cochran-Mantel-Haenszel (CMH) tests to assess whether the proportion of participants at risk for inadequate or excessive intake significantly differed across sociodemographic and weight-related characteristics. Analyses were conducted separately for each dietary assessment methodology and separately for food compared with food and supplements. For several micronutrients and demographic subgroups, the proportion of participants with inadequate or excessive intake was close to zero; thus, asymptotic methods were not valid. We utilized a permutation-based method to assess statistically significant differences (34). For ordered variables, an exact CMH test was used; for the unordered variable of race/ethnicity, a Monte Carlo CMH test was used (35). For each methodology and demographic variable where at least 1 proportion was non-zero, we report the P value for a difference in proportions across groups. When all proportions were exactly zero (i.e., no participants at risk in any group), no P value is reported. We interpret statistical significance with a Bonferroni-corrected α level of 0.05/19 micronutrients = 0.0026 for inadequate intake and 0.05/12 micronutrients = 0.0042 for excessive intake. Among statistically significant results, we considered a result relevant to public health when the proportion at risk differs by ≥10%.

Results

Cohort-level characteristics are presented in Table 1, and participant-level characteristics combined across all cohorts are presented in **Table 2**. Just over half of the participants were non-Hispanic White (57%) or had earned a 4-y college degree or higher (51%). Mean prepregnancy BMI was 26.3, and few (<10%) experienced pregnancy complications related to diabetes, hypertension, or pre-eclampsia. Mean gestational age at assessment was 23 wk (range: 5–40 wk). Among cohorts with dietary supplement data, >99% of participants reported dietary supplement use in pregnancy. Participant characteristics were similarly distributed between those completing recalls and FFQs.

Risk of inadequate daily intake

The percentage of participants at risk of inadequate daily intake is presented in **Supplemental Figure 1** (vitamins with and without dietary supplements), **Supplemental Figure 2** (minerals with and without dietary supplements), **Supplemental Table 1** (food intake only), and **Supplemental Table 2** (food and dietary supplements), stratified by dietary assessment methodology. Regardless of methodology, approximately 1 in 5 participants or fewer were at risk of inadequate daily intake of riboflavin, niacin, vitamin B-12, and phosphorus, based on food sources alone, which decreased to very few participants (~5% or fewer) when dietary supplement use was considered. Approximately one-quarter to one-third of participants were at risk of inadequate daily intake of vitamins A and C, thiamin, vitamin B-6, copper, calcium, and zinc from food sources alone, although estimates of inadequacy for vitamin C were notably higher when based on recall methods (49% vs. 20% for FFQ). Use of dietary supplements reduced the risk of inadequacy to ~5% or less for vitamins A, C, and B-6, and zinc for both methodologies, and also for thiamin, calcium, and copper based on recall methodology. Risk of inadequacy remained at 10–20%

TABLE 2 Participant characteristics at the time of dietary assessment[1]

	All participants ($n = 9801$)		Recall participants ($n = 1910$)		FFQ participants ($n = 7891$)	
	Mean or *n*	SD or %	Mean or *n*	SD or %	Mean or *n*	SD or %
Maternal age, y	30.2	(5.9)	28.2	(6.0)	30.6	(5.7)
14–18 y	182	(2%)	93	(5%)	89	(1%)
19–30 y	4728	(48%)	1050	(55%)	3678	(47%)
31–50 y	4786	(49%)	715	(37%)	4071	(52%)
Missing	105	(1%)	52	(3%)	53	(1%)
Maternal race/ethnicity						
Hispanic, any race	1830	(19%)	516	(27%)	1314	(17%)
Non-Hispanic White	5442	(56%)	930	(49%)	4512	(57%)
Non-Hispanic Black	1543	(16%)	290	(15%)	1253	(16%)
Non-Hispanic other	718	(7%)	149	(8%)	569	(7%)
Missing	268	(3%)	25	(1%)	243	(3%)
Maternal education						
<High school degree	759	(8%)	263	(14%)	496	(6%)
High school diploma or GED	1794	(18%)	400	(21%)	1394	(18%)
Some college or 2-y degree	2197	(22%)	417	(22%)	1780	(23%)
4-y degree or more	4969	(51%)	793	(42%)	4176	(53%)
Missing	82	(1%)	37	(2%)	45	(1%)
Maternal prepregnancy BMI, kg/m^2	26.3	(6.4)	26.2	(6.5)	26.3	(6.4)
Underweight (<18.5)	342	(3%)	98	(5%)	244	(3%)
Normal (18.5–24.9)	4777	(49%)	924	(48%)	3,853	(49%)
Overweight (25–29.9)	2367	(24%)	460	(24%)	1907	(24%)
Obese (≥30)	2212	(23%)	428	(22%)	1784	(23%)
Missing	103	(1%)	0	(0%)	103	(1%)
Pregestational diabetes	114	(1%)	8	(0%)	106	(1%)
Gestational diabetes	614	(6%)	77	(4%)	537	(7%)
Pre-eclampsia or gestational hypertension	879	(9%)	147	(8%)	732	(9%)
Prenatal smoking	727	(7%)	151	(8%)	576	(7%)

[1]Values are means (SDs) or *n* (%). For participants who reported prenatal dietary intake data retrospectively at 2–5 y after delivery ($n = 508$ FFQ participants), age and prepregnancy BMI in early pregnancy were obtained from medical records and education at the time of pregnancy was recalled retrospectively at 2–5 y after delivery. FFQ, food-frequency questionnaire; GED, graduate equivalency degree.

for thiamin, calcium, and copper, even with dietary supplement use based on FFQ methods. Approximately half of participants were at risk of inadequate daily intake of folate and magnesium based on food intake alone, with higher risk for folate based on FFQ methods (59% vs. 41% for recall). Dietary supplement use greatly reduced risk for folate (down to 11% for FFQs, 0% for recalls) but not magnesium (~40%). The majority of participants (>70%) were at risk of inadequate daily intake of vitamins E and D and iron based on food alone; with dietary supplements, up to 20% of participants remained at risk for inadequate vitamin E and iron intake, and up to 40% for inadequate vitamin D intake.

The percentage of participants with daily vitamin K intake exceeding the AI based on food alone was higher with FFQs (73%) than recalls (43%), but dietary supplement use resulted in the majority of participants exceeding the AI for both methods (75% and 63%, respectively). Less than half of participants had daily potassium intakes above the AI based on food alone (36–43%), which did not notably increase with dietary supplement use (37–53%).

Risk of excessive daily intake

The percentage of participants at risk of excessive daily intake is presented in **Supplemental Figure 3** (with and without dietary supplements), Supplemental Table 1 (food intake only) and Supplemental Table 2 (food and dietary supplements), stratified by dietary assessment methodology. Regardless of methodology, almost no participants (≤5%) were at risk of excessive daily intake of any micronutrient based on foods alone. With dietary supplement use, risk of excessive daily intake was notable for folic acid (32% based on FFQ, 51% based on recall), iron (~40%), and zinc (~20%).

Disparities in risks

Risks of inadequate daily intake according to sociodemographic characteristics are presented in Table 3 (food intake only) and Table 4 (food and dietary supplements) for nutrients that were statistically significant and deemed relevant to public health. Full results are presented in **Supplemental Tables 3–10**, stratified by dietary assessment methodology.

Age

For both assessment methodologies, more younger participants (14–18 y) had intakes below the EAR for phosphorus and above the AI for vitamin K from food alone (Supplemental Table 3) and with dietary supplements (Supplemental Table 4). Similar age-related disparities were also evident for vitamin A, calcium, copper, magnesium, and potassium with recall methods only. Risks of excessive daily intake did not differ by age for any nutrient with either methodology.

Race/ethnicity

The risk of not meeting the EAR or AI on food alone varied by race/ethnicity for vitamins A, E, and B-6, folate, calcium, copper, magnesium, vitamin K, and potassium based on recall methods, and for calcium, zinc, and vitamin K based on FFQ methods (Supplemental Table 5). Regardless of methodology, non-Hispanic White participants were at the lowest risk of inadequate intakes. When nutrients from dietary supplements were considered (Supplemental Table 6), disparities persisted for vitamin E with both methods, with non-Hispanic White and Black participants at lowest risk. Disparities also persisted with recall methods for calcium, copper, magnesium, vitamin K, and potassium with recall methods, again with non-Hispanic White participants at the lowest risk of inadequate intake. Disparities

TABLE 3 Disparities in risk of inadequate intake of micronutrients in ECHO pregnant females based on food intake alone[1]

	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*P*
	24-Hour dietary recalls, *n* and % at risk										
Age disparities	Overall		14–18 y		19–30 y		31–50 y				
% below EAR											
Vitamin A (μg/d)	1910	42%	93	53%	1031	45%	734	37%	—	—	<0.001[2]
Calcium (mg/d)	1910	34%	93	59%	1031	36%	734	30%	—	—	<0.001[2]
Copper (μg/d)	1910	24%	93	38%	1031	27%	734	18%	—	—	<0.001[2]
Magnesium (mg/d)	1910	53%	93	81%	1031	57%	734	47%	—	—	<0.001[2]
Phosphorus (mg/d)	1910	6%	93	40%	1031	7%	734	5%	—	—	<0.001[2]
% above AI											
Vitamin K (μg/d)	1910	43%	93	37%	1031	39%	734	50%	—	—	<0.001[2]
Racial/ethnic disparities	Overall		Hispanic		NH White		NH Black		Other		
% below EAR											
Vitamin A (μg/d)	1910	42%	516	49%	930	33%	290	50%	149	46%	<0.001[2]
Vitamin E (mg/day)	1910	73%	516	80%	930	68%	290	76%	149	73%	<0.001[2]
Vitamin B-6 (mg/d)	1910	17%	516	17%	930	15%	290	23%	149	3%	<0.001[2]
Folate, B-9 (μg/d)	1910	41%	516	47%	930	36%	290	44%	149	44%	<0.001[2]
Calcium (mg/d)	1910	34%	516	22%	930	8%	290	21%	149	20%	<0.001[2]
Copper (μg/d)	1910	24%	516	32%	930	18%	290	31%	149	23%	<0.001[2]
Magnesium (mg/d)	1910	53%	516	61%	930	45%	290	65%	149	56%	<0.001[2]
Zinc (mg/d)	1910	38%	516	42%	930	36%	290	38%	149	41%	0.25
% above AI											
Vitamin K (μg/d)	1910	43%	516	34%	930	50%	290	37%	149	43%	<0.001[2]
Potassium (mg/d)	1909	36%	516	35%	930	42%	289	31%	149	37%	<0.001[2]
Educational disparities	Overall		<HS		HS or GED		Some college		≥4 y degree		
% below EAR											
Vitamin A (μg/d)	1910	42%	263	53%	400	47%	417	43%	793	32%	<0.001[2]
Vitamin E (mg/d)	1910	73%	263	80%	400	78%	417	76%	793	64%	<0.001[2]
Riboflavin, B-2 (mg/d)	1910	18%	263	23%	400	19%	417	19%	793	13%	<0.001[2]
Vitamin B-6 (mg/d)	1910	17%	263	24%	400	16%	417	18%	793	14%	<0.001[2]
Calcium (mg/d)	1910	34%	263	22%	400	9%	417	19%	793	9%	<0.001[2]
Copper (μg/d)	1910	24%	263	33%	400	29%	417	24%	793	14%	<0.001[2]
Magnesium (mg/d)	1910	53%	263	66%	400	61%	417	57%	793	38%	<0.001[2]
% above AI											
Vitamin K (μg/d)	1910	43%	263	31%	400	36%	417	39%	793	56%	<0.001[2]
Potassium (mg/d)	1909	36%	263	24%	399	22%	417	33%	793	46%	<0.001[2]

(*Continued*)

TABLE 3 (*Continued*)

BMI disparities	Overall		Underweight		Normal		Overweight		Obese		
% below EAR											
Vitamin A (μg/d)	1910	42%	98	38%	924	39%	460	42%	428	48%	<0.001[2]
Vitamin C (mg/d)	1910	49%	98	11%	924	21%	460	24%	428	30%	<0.001[2]
Vitamin E (mg/d)	1910	73%	98	69%	924	69%	460	74%	428	79%	<0.001[2]
Thiamin, B-1 (mg/d)	1910	28%	98	22%	924	26%	460	29%	428	32%	<0.001[2]
Vitamin B-6 (mg/d)	1910	17%	98	3%	924	15%	460	19%	428	22%	<0.001[2]
Folate, B-9 (μg/d)	1910	41%	98	32%	924	39%	460	43%	428	46%	<0.001[2]
Magnesium (mg/d)	1910	53%	98	48%	924	48%	460	53%	428	61%	<0.001[2]
% above AI											
Vitamin K (μg/d)	1910	43%	98	43%	924	49%	460	42%	428	36%	<0.001[2]
Potassium (mg/d)	1909	36%	98	40%	923	41%	460	35%	428	24%	<0.001[2]
	Food-frequency questionnaires										
Age disparities	Overall		14–18 y		19–30 y		31–50 y				
% below EAR											
Vitamin A (μg/d)	7767	31%	87	39%	3315	34%	4312	30%	—	—	0.14
Calcium (mg/d)	7891	38%	89	51%	3353	38%	4396	39%	—	—	0.17
Copper (μg/d)	7891	16%	89	16%	3353	17%	4396	15%	—	—	0.69
Magnesium (mg/d)	7891	47%	89	63%	3353	49%	4396	49%	—	—	0.10
Phosphorus (mg/d)	7891	7%	89	34%	3353	7%	4396	7%	—	—	<0.001[2]
% above AI											
Vitamin K (μg/d)	7696	73%	89	67%	3315	68%	4241	78%	—	—	0.004
Racial/ethnic disparities	Overall		Hispanic		NH White		NH Black		Other		
% below EAR											
Vitamin A (μg/d)	7767	31%	1299	36%	4462	29%	1214	33%	560	33%	0.03
Vitamin E (mg/d)	7891	69%	1314	75%	4512	66%	1253	75%	569	70%	<0.001
Vitamin B-6 (mg/d)	7891	36%	1314	38%	4512	34%	1253	41%	569	39%	<0.001
Folate, B-9 (μg/d)	7891	59%	1314	60%	4512	57%	1253	64%	569	59%	<0.001
Calcium (mg/d)	7891	38%	1314	38%	4512	35%	1253	45%	569	44%	<0.001[2]
Copper (μg/d)	7891	16%	1314	17%	4512	14%	1253	19%	569	15%	<0.001
Magnesium (mg/d)	7891	47%	1314	50%	4512	44%	1253	53%	569	48%	<0.001
Zinc (mg/d)	7581	37%	1314	38%	4512	34%	943	44%	569	40%	<0.001[2]
% above AI											
Vitamin K (μg/d)	7696	73%	1283	62%	4397	77%	1238	73%	535	75%	<0.001[2]
Potassium (mg/d)	7891	43%	1314	43%	4512	46%	1253	37%	569	38%	<0.001

(*Continued*)

TABLE 3 (*Continued*)

Educational disparities	Overall		<HS		HS or GED		Some college		≥4-y degree		
% below EAR											
Vitamin A (μg/d)	7767	31%	487	34%	1379	33%	1745	32%	4119	30%	0.14
Vitamin E (mg/d)	7891	69%	496	72%	1394	73%	1780	72%	4176	67%	0.001
Riboflavin, B-2 (mg/d)	7891	18%	496	16%	1394	17%	1780	18%	4176	18%	0.62
Vitamin B-6 (mg/d)	7891	36%	496	35%	1394	36%	1780	37%	4176	36%	0.93
Calcium (mg/d)	7891	38%	496	34%	1394	37%	1780	39%	4176	39%	0.40
Copper (μg/d)	7891	16%	496	14%	1394	17%	1780	17%	4176	15%	0.23
Magnesium (mg/d)	7891	47%	496	46%	1394	48%	1780	49%	4176	46%	0.24
% above AI											
Vitamin K (μg/d)	7696	73%	488	62%	1379	67%	1727	71%	4059	78	<0.001[2]
Potassium (mg/d)	7891	43%	496	49%	1394	45%	1780	42%	4176	42	0.21
BMI disparities	Overall		Underweight		Normal		Overweight		Obese		
% below EAR											
Vitamin A (μg/d)	7767	31%	241	29%	3782	30%	1878	32%	1766	34%	0.05
Vitamin C (mg/d)	7891	20%	244	18%	3853	20%	1907	21%	1784	21%	0.56
Vitamin E (mg/d)	7891	69%	244	67%	3853	67%	1907	71%	1784	73%	0.02
Thiamin, B-1 (mg/d)	7891	32%	244	27%	3853	30%	1907	32%	1784	34%	0.03
Vitamin B-6 (mg/d)	7891	36%	244	35%	3853	34%	1907	37%	1784	39%	0.06
Folate, B-9 (μg/d)	7891	59%	244	56%	3853	56%	1907	60%	1784	62%	<0.001
Magnesium (mg/d)	7891	47%	244	42%	3853	44%	1907	49%	1784	50%	0.06
% above AI											
Vitamin K (μg/d)	7696	73%	240	72%	3770	76%	1864	71%	1724	71%	0.40
Potassium (mg/d)	7891	43%	244	48%	3853	44%	1907	42%	1784	42%	0.39

[1]AI, Adequate Intake; EAR, Estimated Average Requirement; ECHO, Environmental influences on Child Health Outcomes; GED, general education degree; HS, high school diploma; NH, non-Hispanic.
[2]Statistical significance defined by Bonferroni-corrected α level of 0.05/19 micronutrients = 0.0026 for inadequate intake. Among statistically significant results, we consider a result relevant to public health when the proportion at risk differs by ≥10%.

TABLE 4 Disparities in risk of inadequate intake of micronutrients in ECHO pregnant females based on food intake and use of any dietary supplements[1]

	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*P*
	24-Hour dietary recalls, n and % at risk										
Age disparities	Overall		14–18 y		19–30 y		31–50 y				
% below EAR											
Calcium (mg/d)	1427	5%	93	29%	791	6%	500	3%	—	—	<0.001[2]
Copper (μg/d)	1427	6%	93	17%	791	6%	500	3%	—	—	<0.001[2]
Magnesium (mg/d)	1427	39%	93	91%	791	47%	500	27%	—	—	<0.001[2]
Phosphorus (mg/d)	1427	0%	93	24%	791	0%	500	0%	—	—	<0.001[2]
% above AI											
Vitamin K (μg/d)	1427	63%	93	40%	791	51%	500	81%	—	—	<0.001[2]
Potassium (mg/d)	1426	37%	93	36%	790	32%	500	46%	—	—	<0.001[2]
Racial/ethnic disparities	Overall		Hispanic		NH White		NH Black		Other		
% below EAR											
Vitamin E (mg/d)	1427	17%	350	26%	731	14%	209	12%	137	29%	<0.001[2]
Calcium (mg/d)	1427	5%	350	11%	731	2%	209	7%	137	7%	<0.001[2]
Copper (μg/d)	1427	6%	350	12%	731	3%	209	5%	137	9%	<0.001[2]
Magnesium (mg/d)	1427	39%	350	53%	731	27%	209	65%	137	56%	<0.001[2]
% above AI											
Vitamin K (μg/d)	1427	63%	350	41%	731	74%	209	50%	137	54%	<0.001[2]
Potassium (mg/d)	1426	37%	350	32%	731	42%	208	29%	137	30%	<0.001[2]
Educational disparities	Overall		<HS		HS or GED		Some college		≥4-y degree		
% below EAR											
Vitamin E (mg/d)	1427	17%	220	26%	267	18%	337	19%	602	13%	<0.001[2]
Calcium (mg/d)	1427	5%	220	12%	267	1%	337	9%	602	2%	<0.001[2]
Copper (μg/d)	1427	6%	220	13%	267	6%	337	7%	602	2%	<0.001[2]
Magnesium (mg/d)	1427	39%	220	67%	267	55%	337	53%	602	24%	<0.001[2]
Phosphorus (mg/d)	1427	0%	220	0%	267	0%	337	0%	602	0%	—
% above AI											
Vitamin K (μg/d)	1427	63%	220	26%	267	38%	337	47%	602	83%	<0.001[2]
Potassium (mg/d)	1426	37%	220	25%	266	24%	337	34%	602	46%	<0.001[2]
BMI disparities	Overall		Underweight		Normal weight		Overweight		Obese		
% below EAR											
Magnesium (mg/d)	1427	39%	51	32%	731	34%	351	47%	294	57%	<0.001[2]
% above AI											
Vitamin K (μg/d)	1427	63%	51	54%	731	71%	351	57%	294	43%	<0.001[2]
Potassium (mg/d)	1426	37%	51	53%	730	40%	351	35%	294	27%	<0.001[2]

(*Continued*)

TABLE 4 (*Continued*)

	Food-frequency questionnaires										
Age disparities	Overall		14–18 y		19–30 y		31–50 y				
% below EAR											
Calcium (mg/d)	5606	22%	87	37%	2403	23%	3065	22%	—	—	0.05
Copper (μg/d)	4731	20%	85	21%	2134	21%	2461	18%	—	—	0.49
Magnesium (mg/d)	4731	41%	85	57%	2134	42%	2461	41%	—	—	0.04
Phosphorus (mg/d)	1872	1%	14	44%	443	2%	1415	1%	—	—	<0.001[2]
% above AI											
Vitamin K (μg/d)	2532	75%	18	62%	710	69%	1804	79%	—	—	<0.001[2]
Potassium (mg/d)	2532	53%	18	59%	710	50%	1804	54%	—	—	0.16
Racial/ethnic disparities	Overall		Hispanic		NH White		NH Black		Other		
% below EAR											
Vitamin E (mg/d)	5609	22%	895	29%	2991	18%	1194	25%	363	22%	<0.001[2]
Calcium (mg/d)	5606	22%	895	22%	2990	19%	1193	26%	362	25%	<0.001
Copper (μg/d)	4731	20%	717	23%	2479	18%	1143	21%	226	18%	0.07
Magnesium (mg/d)	4731	41%	717	43%	2479	36%	1143	45%	226	41%	<0.001
% above AI											
Vitamin K (μg/d)	2532	75%	446	64%	1546	78%	289	77%	183	81%	0.03
Potassium (mg/d)	2532	53%	446	56%	1546	53%	289	46%	183	48%	0.03
Educational disparities	Overall		<HS		HS or GED		Some college		≥4-y degree		
% below EAR											
Vitamin E (mg/d)	5609	22%	462	29%	1164	25%	1172	24%	2779	18%	<0.001[2]
Calcium (mg/d)	5606	22%	462	22%	1164	23%	1170	23%	2778	22%	0.61
Copper (μg/d)	4731	20%	426	22%	1079	21%	874	21%	2322	18%	0.14
Magnesium (mg/d)	4731	41%	426	41%	1079	41%	874	43%	2322	40%	0.56
Phosphorus (mg/d)	1872	1%	41	27%	146	6%	406	2%	1271	1%	<0.001[2]
% above AI											
Vitamin K (μg/d)	2532	75%	114	62%	260	62%	514	72%	1621	80%	<0.001[2]
Potassium (mg/d)	2532	53%	114	58%	260	50%	514	51%	1621	53%	0.77
BMI disparities	Overall		Underweight		Normal weight		Overweight		Obese		
% below EAR											
Magnesium (mg/d)	4731	41%	174	35%	2406	39%	1082	44%	1037	43%	0.62
% above AI											
Vitamin K (μg/d)	2532	75%	88	76%	1465	78%	573	71%	399	71%	0.41
Potassium (mg/d)	2532	53%	88	51%	1465	54%	573	50%	399	52%	0.74

[1] AI, Adequate Intake; EAR, Estimated Average Requirement; ECHO, Environmental influences on Child Health Outcomes; GED, general education degree; HS, high school diploma; NH, non-Hispanic.
[2] Statistical significance defined by Bonferroni-corrected α level of 0.05/19 micronutrients = 0.0026 for inadequate intake. Among statistically significant results, we consider a result relevant to public health when the proportion at risk differs by ≥10%.

in risks of excessive daily intake were evident from recall methods only for folic acid ($P = 0.003$), with non-Hispanic Black (57%) and White (53%) participants having higher risks for excessive intake than Hispanic (43%) or other race/ethnicity (47%) participants.

Education

The risk of inadequacy based on food only varied by education for vitamins A and E, riboflavin, vitamin B-6, calcium, copper, and magnesium using recall data only, with college-educated participants having the lowest risks (Supplemental Table 7). Similarly, more participants with 4-y degrees exceeded the AI for vitamin K using both assessment methods and potassium with recalls only. When nutrients from dietary supplements were considered (Supplemental Table 8), participants without a high school education were at disparately higher risk for inadequate daily intake for vitamin E based on both methods; for calcium, copper, and magnesium based on recalls only; and for phosphorus based on FFQs only. A greater percentage of participants having at least some college education exceeded the AI for vitamin K (both methods) and potassium (recalls only). Risk of excessive daily intake did not vary by education for any nutrient with either methodology.

Prepregnancy BMI

Risks of inadequate daily intake varied by prepregnancy BMI for vitamins A, C, and E, thiamin, vitamin B-6, folate, and magnesium based on recall methods; no disparities in risks were evident based on FFQ methods (Supplemental Table 9). Participants with obesity were at highest risk of inadequate daily intake of these nutrients, followed by participants with overweight. Fewer participants with obesity, and with overweight to a lesser degree, exceeded the AI for vitamin K and potassium. These weight-related disparities persisted with dietary supplements only for magnesium, vitamin K, and potassium. Risk of excessive daily intake did not vary by prepregnancy BMI for any nutrient with either methodology.

Discussion

In this diverse sample of nearly 10,000 pregnant females across the United States, we report substantial risk of inadequacy for multiple nutrients from food alone, underscoring the need to improve diet quality of pregnant females and use dietary supplements when appropriate. Particularly at risk for inadequate daily intake were participants who were aged 14–18 y, identified as Hispanic, Black, or other races/ethnicities (i.e., not non-Hispanic White), had less than a high school education, or had overweight or obesity before pregnancy. Dietary supplement use attenuated all disparities in risks for inadequate intakes of vitamins A and C, thiamin, riboflavin, vitamin B-6, folate, and zinc, and the BMI disparities for vitamin E. However, disparities in risks of inadequate intake by at least 1 sociodemographic or weight-related characteristic persisted even with dietary supplements for vitamin E, calcium, copper, magnesium, phosphorus, vitamin K, and potassium. This work highlights the variability in how well dietary supplements address the gap between food-based micronutrient daily intake and DRIs for pregnant females. As our results mirror intake disparities evident in nonpregnant adults (36–38), pregnancy may be an important opportunity to address persistent gaps in nutrient intake given increased contact with providers and often heightened attention to their diet and health.

Very few participants in our study (<5%) were at risk of excessive daily intake for any micronutrient based on food alone, but this increased with dietary supplement use, most notably for iron (~40%), folic acid (>30%), and zinc (~20%), similar to a recent NHANES analysis (10). A U-shaped relation between iron and reproductive outcomes has been previously reported, with excessive daily intake associated with increased risk of low birth weight, small-for-gestational age neonates, and (inconsistently) gestational diabetes (39). Excessive folic acid intake is concerning as animal studies indicate high intakes may increase offspring cardiometabolic risks through altered DNA methylation (40, 41), and emerging human studies affirm that maternal folic acid intake may affect offspring DNA methylation (42, 43). While effects of epigenetic shifts on offspring outcomes are not well understood, our results emphasize the urgency of understanding the impact of widespread excessive folic acid intake. This is especially important for females of non-Hispanic Black race/ethnicity, who were at the highest risk of excessive daily intake of folic acid with dietary supplement use and already experience disparities in obesity, diabetes, and cardiovascular diseases (44–46).

Importantly, disparities in risks of inadequate daily intake remained with dietary supplement use, albeit much reduced compared with food alone, suggesting personalized approaches for dietary counseling and dietary supplement recommendations are needed. Yet, this would be challenging for busy clinicians who are not equipped to assess prenatal dietary intake and provide individualized advice (47). While registered dietitian nutritionists could assess intake and provide personalized recommendations to pregnant women, availability and reimbursement for such services varies [only 50% of states reimburse these services for Medicaid beneficiaries (48)]. For both clinical counseling and public health messaging, it would be beneficial to identify key food groups to increase and the specific dietary supplements best formulated to address common micronutrient shortfalls without inducing excess intake. Improved diet during pregnancy has been difficult to achieve (49), particularly very early in pregnancy, a critical period of fetal development; therefore, increased efforts to improve maternal micronutrient intake prior to pregnancy are critical.

The implications of having ≥1 of 5 females at risk of inadequate daily intake of vitamins D, E, and K, choline, magnesium, and potassium alone or in combination in terms of offspring health are relatively unknown. Magnesium supplementation of up to 400 mg/d in generally healthy pregnant females has not consistently affected blood pressure, pre-eclampsia, intrauterine growth restriction, or preterm delivery (50–52); however, baseline magnesium intake was not reported in these studies, so it is unclear if intake was low without supplementation (50–52), and blood concentrations of magnesium did not differ between groups post-treatment (50). There is emerging evidence that choline supplementation to achieve daily intakes of 480 to >900 mg/d (well above the AI of 450 mg/d) may benefit offspring cognitive and behavioral outcomes (53, 54), which may be highly relevant given that <25% of our participants exceeded the AI for choline. As most dietary supplements in the United States contain very little choline (10, 55), increased consumption of choline-rich food (eggs, other protein sources) (56) in pregnancy is needed to address the relatively low intakes. Vitamins K and E and potassium have been so understudied in relation to pregnancy outcomes that the DRIs for these nutrients are based on needs for nonpregnant females (57–59).

Further research is needed to evaluate whether the disparities in micronutrient intake observed here contribute to adverse pregnancy outcomes or intergenerational inequalities in health risks and chronic disease.

Our overall results align with a recent report of intake among pregnant women in the United States estimated from 2001–2014 NHANES data (10), even though enrollment into ECHO was not designed to be nationally representative. Our sample was 10-fold larger than the NHANES sample and included data collected over a similar period (1999–2019 vs. 2001–2014) following mandatory folic acid fortification of enriched cereal grain products (60). Racial/ethnic distributions in both studies were similar. Relatively more ECHO participants had earned 4-y college degrees (51% vs. 29%), which likely reflects the willingness of more highly educated individuals to enroll in health research studies (61, 62). Nonetheless, results were similar for food-based nutrient analyses. Differences between the studies are more evident for dietary supplement analyses; risks of inadequate intake were notably lower in ECHO for vitamins A, C, D, E, and B-6; folate; vitamin K; and iron; and risks for excessive intake were higher for folic acid, iron, and zinc. These differences are likely driven by the higher prevalence of dietary supplement use in ECHO (>99%) than in the US population of pregnant women (70%), resulting in more of our participants consuming higher levels of these nutrients. Yet, given the similarity in participant characteristics and risks of inadequate or excessive intake, the ECHO consortium is well positioned to provide nationally relevant data from a large sample of pregnant participants on prenatal micronutrient intake and subsequent effects on offspring outcomes. Moreover, our study extends the NHANES analysis by highlighting subgroups at disparately higher risk of inadequate or excessive micronutrient intake in pregnancy, an analysis that requires a large, diverse sample.

Limitations of our study include potential underreporting (63) of intake for all methods and analysis of FFQ data given that recalls are preferred for evaluating proportions above/below thresholds (27), especially given evidence that FFQs may overestimate micronutrient intake relative to recalls (64) and biomarker recovery studies (65). There was notable heterogeneity in the FFQs utilized; however, all were validated previously (19–25, 64). Variability in nutrient estimates across databases could have contributed to error in our estimates, especially when supplement data were estimated with mean nutrient values for each type of supplement rather than brand/type. Despite the use of different methodologies and nutrient databases across cohorts and over time, food-based results were similar between methodologies (±10%) for most nutrients, including directionality in disparity analyses (even though statistical significance was not similarly reached). Results with dietary supplements varied more between methodologies, but sample sizes varied across analyses and direct comparisons should be interpreted with caution. We had data from relatively fewer participants aged 14–18 y, with other races/ethnicities (i.e., not Hispanic, White, or Black), or underweight BMI, especially in dietary supplement analyses, which limits the interpretation of findings for these subgroups. Some disparity in findings may be due to type 1 error arising from multiple comparisons, even with adjusted thresholds for interpretation. One cohort retrospectively assessed prenatal diet at 2–5 y postpartum, which may be subject to more recall error and actually represent the postpartum diet more than prenatal diet; however, prior studies have shown that dietary intake changes little from pregnancy to postpartum (66, 67). We also did not consider clustering of inadequate or excessive intakes across micronutrients or subpopulations, which could be informative for targeted efforts to improve comprehensive intake. Analysis of differences by trimester or over time was beyond the scope of this paper, but should be examined by future studies. Last, we did not consider bioavailability or solubility of micronutrients from fortified food and dietary supplements, which has implications for downstream effects on maternal/child outcomes. We note that there is often a discrepancy between population prevalence of nutritional risk when dietary intakes are used compared with when biomarkers are used (68). This is complicated further by our focus on pregnancy because reference ranges for nutritional biomarkers in this state can differ from nonpregnancy because of hemodilution and other changes that occur during pregnancy (69). The ECHO consortium is well positioned to conduct futures studies of circulating biomarkers in pregnancy, and thereby address knowledge gaps about associations with reported intake and maternal/offspring health outcomes.

In summary, our study highlights suboptimal daily intake of multiple micronutrients during pregnancy in the United States, and notable disparities in risks of inadequate intake even with dietary supplement use according to age, race/ethnicity, education, and prepregnancy BMI. While it is important to clarify how suboptimal daily intake of micronutrients in pregnancy impacts offspring health outcomes, clinicians serving younger or minority pregnant females with obesity or less education should particularly attend to nutritional needs now, including discussion of dietary habits and use of dietary supplements. Increased consumption of foods rich in nutrients commonly underconsumed is critical. Reformulation of prenatal dietary supplements may also be needed to address these shortfalls while reducing excessive intakes of folic acid, iron, and zinc.

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