Association of food insecurity with dietary intakes and nutritional biomarkers among US children, National Health and Nutrition Examination Survey (NHANES) 2011–2016

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ABSTRACT

Background: Food insecurity is associated with poorer nutrient intakes from food sources and lower dietary supplement use. However, its association with total usual nutrient intakes, inclusive of dietary supplements, and biomarkers of nutritional status among US children remains unknown.

Objective: The objective was to assess total usual nutrient intakes, Healthy Eating Index-2015 (HEI-2015) scores, and nutritional biomarkers by food security status, sex, and age among US children.

Methods: Cross-sectional data from 9147 children aged 1–18 y from the 2011–2016 NHANES were analyzed. Usual energy and total nutrient intakes and HEI-2015 scores were estimated using the National Cancer Institute method from 24-h dietary recalls.

Results: Overall diet quality was poor, and intakes of sodium, added sugars, and saturated fat were higher than recommended limits, regardless of food security status. Food-insecure girls and boys were at higher risk of inadequate intakes for vitamin D and magnesium, and girls also had higher risk for inadequate calcium intakes compared with their food-secure counterparts, when total intakes were examined. Choline intakes of food-insecure children were less likely to meet the adequate intake than those of their food-secure peers. No differences by food security status were noted for folate, vitamin C, iron, zinc, potassium, and sodium intakes. Food-insecure adolescent girls aged 14–18 y were at higher risk of micronutrient inadequacies than any other subgroup, with 92.8% (SE: 3.6%) at risk of inadequate intakes for vitamin D. No differences in biomarkers for vitamin D, folate, iron, and zinc were observed by food security status. The prevalence of iron deficiency was 12.7% in food-secure and 12.0% in food-insecure adolescent girls.

Conclusions: Food insecurity was associated with compromised intake of some micronutrients, especially among adolescent girls. These results highlight a need for targeted interventions to improve children's overall diet quality, including the reduction of specific nutrient inadequacies, especially among food-insecure children. This study was registered at clinicaltrials.gov as NCT03400436. *Am J Clin Nutr* 2021;114:1059–1069.

Keywords: NHANES, children, food security, total usual nutrient intake, Healthy Eating Index, iron deficiency

Introduction

Food insecurity is the lack of consistent access to adequate and safe foods for an active and healthy life due to limited resources for food (1). The risk of household food insecurity is associated with many factors, including low income, unemployment, and the presence of children in the household (1). Despite higher prevalence of food insecurity among households with children than those without children, children are less likely to be food-insecure than adults in the same household, purportedly because adults may shield or buffer children from the impact of the household's limited resources (2, 3). Yet, food-insecure children are more likely to have developmental delays and poorer physical and mental health than their food-secure counterparts (4–9), and these deficits may present long-term health and disease risks (10).

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Supplemental Tables 1–5 and Supplemental Figure 1 are available from the "Supplemental data" link in the online posting of the article at https://academic.oup.com/ajcn/.

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Abbreviations used: AI, adequate intake; CDRR, chronic disease risk reduction intake; DGA, Dietary Guidelines for Americans; DRI, dietary reference intakes; DSMQ, dietary supplement and prescription medication questionnaire; EAR, estimated average requirement; HEI, Healthy Eating Index; NCI, National Cancer Institute; NSLP/BP, National School Lunch Program and National School Breakfast Program; PIR, family poverty-to-income ratio; SNAP, Supplemental Nutrition Assistance Program; UL, tolerable upper intake level; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children; 25(OH)D, 25-hydroxyvitamin D.

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The concept and measurement of food security are inherently linked to diet quality and quantity, which may partially mediate the association between food insecurity and adverse health conditions. Therefore, many studies have assessed nutrient intakes of food-insecure children in order to identify the gaps between the amounts of nutrients consumed and recommended intakes (i.e., nutrient gaps). Previous findings suggest that a considerable number of nutrient gaps exist among food-insecure adolescents, and a smaller but important number of gaps exist among younger children both in terms of food groups and nutrients (11–13). Dietary supplement use is lower among food-insecure than food-secure children (14), which may further widen the disparities in nutrient intakes (15). However, little is known about total usual nutrient intakes from foods and supplements of food-secure and food-insecure children. Therefore, this study assessed total usual nutrient intakes, selected biomarkers of nutritional status (vitamin D, folate, iron, and zinc), and scores of the Healthy Eating Index-2015 (HEI-2015), a diet quality index, by food security status (food secure and food insecure), sex, and age among US children aged 1–18 y.

Methods

The NHANES is a continuous, cross-sectional series of surveys of nationally representative samples of the resident, civilian, noninstitutionalized US population (16). Data collection in the NHANES consisted of an in-home interview, a health examination in the mobile examination center (MEC), and a follow-up telephone interview. All of the survey protocols were approved by the research ethics review board at the National Center for Health Statistics, and written informed consent was obtained from the participants or their proxies. We combined the 3 most recently available survey cycles (i.e., 2011–2012, 2013–2014, and 2015–2016) with food security and dietary data to increase the reliability and stability of estimates across subgroups (17). The analytic sample included children aged 1–18 y with complete food security data (i.e., either household food security or child food security) and $\geq$1 reliable 24-h dietary recall ($n = 9147$) (**Supplementary Figure 1**).

Sociodemographic variables

Demographic and socioeconomic information was collected during the in-home interview, using the Computer-Assisted Personal Interview system. A proxy provided information for those aged $\leq$15 y, and individuals aged $\geq$16 y answered the questions for themselves. Age in years was categorized according to the Dietary Reference Intake (DRI) age groups: 1–3, 4–8, 9–13, and 14–18 y (18). Self-reported race/Hispanic origin categories were as follows: non-Hispanic white, non-Hispanic black, non-Hispanic Asian, Hispanic, and "other" races. Household education level, defined as the education level of household reference person who owns or rents the residence, was categorized as less than high school, high school graduate or equivalent, some college or associate degree, and college graduate or above. The family poverty-to-income ratio (PIR) is the ratio of the annual family income to the poverty guideline set by the Department of Health and Human Services (19). The PIR has been used as an indicator of family income level and as an income eligibility criterion for federal nutrition assistance programs. Four PIR categories were constructed: $\leq$1.30, 1.31–1.85, 1.86–3.5, and >3.5. A PIR of $\leq$1.30 indicates potential eligibility for the Supplemental Nutrition Assistance Program (SNAP) that provides cash benefits for foods to low-income households to reduce food insecurity (20). A PIR of $\leq$1.85 is an eligibility criterion for the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) that provides tailored food packages, nutrition education, and health referrals to low-income pregnant and lactating women, infants, and young children aged $\leq$5 y. A cutoff of the PIR of 3.50 has been used in other studies to differentiate middle-income and high-income families (21, 22). The household's current SNAP and WIC participation status variables were used to identify these program participants. The National School Lunch Program and the National School Breakfast Program (NSLP/BP) provide reduced-cost meals to school children in households with a PIR of 1.31–1.85 and free meals to those in households with a PIR $\leq$1.30. Children aged 4 to 18 y receiving either reduced-cost or free lunch or breakfast were identified as NSLP/BP participants (20).

Food security measurement

Food security was measured using the US Household Food Security Survey Module during the in-home interview (23). An adult responded to the 10 items for the entire household and additional 8 items specific to children in the household with children $\leq$17 y. Each question referenced the past 12-mo period. The ranges of experience of the entire household or children in the household were classified into 1 of 4 categories of food security (i.e., high, marginal, low, and very low) per NHANES documentation (24). High and marginal food security categories were merged to classify food security, and low and very low food security categories were merged to classify food insecurity. The food security of household children was used for children aged $\leq$17 y as a more direct and sensitive measure tied to the children's experience and dietary intake (15, 25, 26). For children aged $\leq$17 y who did not have complete information about the food security of household children ($n = 10$) and, for children who were aged 18 y ($n = 424$), the food security status of the household was used to classify their food security status. We conducted sensitivity analyses by restricting the sample to children aged 1–17 y (**Supplementary Table 1**) and also by determining the food security status of all children 1–18 y old by using the food security status of the household only (**Supplementary Table 2**). These analyses resulted in largely consistent findings.

Dietary assessment

Two 24-h dietary recalls were collected using the USDA's Automated Multiple-Pass Method (27); the first 24-h recall was administered in person in the MEC, and the second recall was completed via telephone ~3 to 10 d later. Respondents for the dietary interviews included the following: a proxy for participants aged <6 y; a proxy with the assistance of the child for those aged 6 to 8 y; assistance of a proxy for participants aged 9–11 y; and participants aged 12 y or older who answered by themselves. Additionally, a dietary supplement and prescription medication questionnaire (DSMQ) in tandem with a product inventory was administered during the in-home interview. The time frame for the DSMQ was the previous 30 d. A proxy provided information for children ≤15 y old, and individuals ≥16 y old answered the questions for themselves. For each dietary supplement reported, participants were asked to show containers and to report the consumption frequency, the dose, and the duration of use. If a child took any dietary supplement during the 30-d period, the child was classified as a dietary supplement user. The USDA's Food and Nutrient Database for Dietary Studies and NHANES Dietary Supplement Database were used to calculate daily intakes of energy, nutrients, and other food components. Micronutrients of interest were vitamins A, C, D, and E, potassium, choline, magnesium, calcium, and iron that were identified as under-consumed nutrients by the 2015–2020 Dietary Guidelines for Americans (DGA) (28); and folic acid, zinc, and sodium for which intakes above the tolerable upper intake level (UL) have been observed in certain age groups of children (28, 29). Intakes of vitamins A and E from dietary supplements were not available from the NHANES.

Overall diet quality was characterized by the HEI-2015 score (30). The HEI-2015 is a measure of overall diet quality in terms of adherence to the 2015–2020 DGA (28). The HEI-2015 includes 13 components, including 9 adequacy components (total fruit, whole fruit, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids) and 4 moderation components (refined grains, sodium, added sugars, and saturated fats). The component scores add up to a maximum score of 100, with a higher score indicating higher diet quality. The HEI-2015 assesses densities (i.e., per calorie) of consumed food groups and nutrients rather than absolute amounts and does not account for nutrients from dietary supplements. Because the 2015–2020 DGA applies only to the US population ages ≥2, the HEI-2015 was only calculated for children aged 2–18 y.

Biomarker measurements

Blood samples were collected by trained phlebotomists in the MEC and were analyzed at the CDC laboratory. Details on laboratory methods are described elsewhere (31). Serum 25-hydroxyvitamin D [25(OH)D] was quantified using ultra–HPLC-MS/MS. Vitamin D inadequacy was determined at <40 nmol/L, which is consistent with the estimated average requirement (EAR) (32). The additional cutoffs were also examined as sensitivity analyses: at risk of deficiency (<30 nmol/L) and at risk of not sufficient (<50 nmol/L) (32). Vitamin D can be produced in the skin by sunlight exposure, so we adjusted vitamin D estimates for the season when the sample was collected: winter (November–March) and summer (April–October), as dichotomized per the NHANES protocol. Serum 25(OH)D data were only available in the 2011–2014 NHANES.

Serum zinc was assessed using inductively coupled plasma dynamic reaction cell MS only for participants aged ≥6 y from a one-third subsample. The risk of zinc deficiency was determined using the cutoff values from the Biomarkers of Nutrition for Development Zinc Expert Panel and the International Zinc Nutrition Consultative Group: children aged <10 y (65 μg/dL, morning/nonfasting; 57 μg/dL, afternoon), females aged ≥10 y (70 μg/dL, morning/fasting; 66 μg/dL, morning/fasting; 59 μg/dL, afternoon), and males aged ≥10 y (74 μg/dL, morning/fasting; 70 μg/dL, morning/fasting; 61 μg/dL, afternoon) (33). Per the NHANES protocol, participants aged ≥12 y assigned to a morning session were asked to fast for 9 h, so those who reported ≥9 h of fasting on the fasting questionnaire were classified as fasting.

Whole-blood folate was quantified by microbiologic assay and serum folate was quantified using LC-MS/MS. Then, data from both assays were used to calculate red blood cell folate. Serum folate <10 nmol/L and red blood cell folate <340 nmol/L were defined as folate deficiency on the basis of increased plasma total homocysteine (34).

Serum ferritin was analyzed using electrochemiluminescence immunoassay (Roche Diagnostics), and soluble transferrin receptor was analyzed using particle enhanced immunoturbidimetric assay (Roche Diagnostics). Ferritin and soluble transferrin receptor data were only available in the 2015–2016 NHANES and for participants 1–5 y and females 12–18 y old. Serum ferritin <12 ng/mL for children aged <5 y and <15 ng/mL for those aged ≥5 y are considered to represent depleted iron stores (35). Total body iron was calculated using a formula from Cook and colleagues (36, 37) (in which soluble transferrin receptor is in mg/L and ferritin is in ng/mL); soluble transferrin receptor values obtained through the current NHANES method were converted to those equivalent to the Flowers method that was used in the development of the formula (38, 39). Negative values for total body iron (<0 mg/kg) represent the iron deficit in tissues and, therefore, were considered as iron deficient (36, 37).

$$Total\ body\ iron = -\left\{log_{10}\left(soluble\ transferrin\ receptor \times \frac{1000}{ferritin}\right) - 2.8229\right\}/0.1207 \tag{1}$$

Statistical analyses

The DRI and DGA are intended to be met on average over time; therefore, adherence to these recommendations should be evaluated on the basis of usual intake (i.e., long-term daily average intake). Several methods exist to estimate the distribution of usual intakes from a small number of daily self-reported diet assessments (e.g., 24-h dietary recalls) per individual (40, 41). These methods employ statistical modeling to adjust for random measurement error (e.g., day-to-day variation) and approximate the distribution that would be obtained by averaging many repeated 24-h dietary recalls per individual. For this analysis, total usual nutrient intake distributions were estimated using an adaptation of the National Cancer Institute (NCI) method: "shrink then add" (42). This adapted NCI method incorporates nutrient intake from dietary supplements reported on the DSMQ to estimate distributions of total usual nutrient intake. In brief, nutrient intake from dietary supplements was added to the adjusted usual nutrient intake from foods. Covariates were included for the recall day (Monday–Thursday and Friday–Sunday), sequence of the recall (first and second), dietary supplement use (yes and no), age group (when age groups are combined), and race/Hispanic origin (21). For sensitivity analyses, an additional covariate was added for whether a child was participating in SNAP, WIC, or NSLP/BP to examine whether federal nutrition program participation could explain any of the variation in dietary intakes; however, the addition of federal nutrition program participation had little impact on usual intake estimates (*data not shown*). A balanced repeated replication technique was performed to estimate the SE.

The adapted NCI macro produces means and percentiles of usual intake, and proportions of the group with intakes below or above the DRI standards for adequacy or excess. The percentage of intakes below the EAR was used as an indicator of the percentage at risk of inadequate intake (i.e., the EAR cut-point method) for all nutrients except iron (43). Due to menstrual iron loss among females of reproductive age, the iron requirement distributions are not symmetrical for all sex and life-stage groups, which makes the EAR cut-point method inappropriate. Therefore, we calculated the prevalence of inadequate iron intake using the full probability approach as recommended (44). The DRI report on iron provides the probability of inadequacy at various ranges of usual intake based on the assumption of 18% iron bioavailability. For adolescent girls 14–18 y old, we used the mixed adolescent population distribution that assumes all were menstruating and that 17% were using oral contraceptives (44).

For nutrients with only an adequate intake (AI), the percentage above the AI was calculated to estimate the proportion of children likely to consume a nutrient in sufficient amounts; however, there is no scientific basis to state that the proportion of intakes lower than the AI is an estimate of the prevalence of inadequacy (45). The percentage above the UL indicated the percentage of the population who are potentially at risk of adverse effects from excess nutrient intake. The estimated percentage above the UL was presented only for folic acid and zinc because the percentage above the UL was below 5% for other micronutrients when age groups were combined. Note that the ULs for folate only apply to folic acid, the synthetic form of the vitamin found only in dietary supplements and fortified foods (46). For sodium, the percentage above the chronic disease risk reduction intake (CDRR) was calculated to represent those who would need reductions in sodium intake to reduce chronic disease risk (47). Lastly, the percentage of children whose intakes of added sugars and saturated fats are above the recommended limits (i.e., 10% of total energy intake) was estimated for children 2–18 y old because the 2015–2020 DGA applies only to children $\geq$2 y old (28).

The contribution of dietary supplements to total usual nutrient intake was calculated by dividing mean intake from dietary supplements by mean intake from both foods and dietary supplements for each food security subgroup by sex (48).

Distributions of the HEI-2015 component and total scores were estimated by the multivariate Markov Chain Monte Carlo method, which has been described in detail elsewhere (49), using publicly available SAS macros from the NCI (50). Briefly, the method is an extension of the NCI method that estimates distributions of usual intakes of episodically and nonepisodically consumed dietary components and simultaneously models multiple components. Covariates were included for day of the recall (Monday–Thursday and Friday–Sunday), sequence of the recall (first and second), age group, and race and Hispanic origin based on their associations with dietary intakes. Balanced repeated replication variance estimation was performed to obtain SEs.

All statistical analyses were performed using SAS (version 9.4; SAS Institute Inc.) and SAS-callable SUDAAN (version 11; RTI International) software. Design-based statistical methods were used to account for a complex, multistage sampling design (51). Estimates with a relative SE of >40% were considered unreliable and thus, per the National Center for Health Statistics analytical guidelines, are not displayed. Estimates between food-secure and food-insecure groups were compared by sex using *t*-tests as recommended by the National Center for Health Statistics (52). Statistical significance was determined at a 2-sided P value <0.05. No adjustments were made for multiple comparisons given the exploratory nature of this analysis.

Results

In 2011–2016, 11.9% of boys and 10.8% of girls in the US aged 1–18 y were food insecure (**Table 1**). Compared with food-secure boys and girls, those who experienced food insecurity were more likely to be older; non-Hispanic black or Hispanic; living in a lower-income family (i.e., PIR $\leq$1.30); living in a household where the head of the household had attained a lower educational level (i.e., <high school); living in a household participating in SNAP; and to be a participant in WIC (for 1–4 y) or NSLP/BP (for 4–18 y). Those who experienced food insecurity were also less likely to take dietary supplements than those who experienced food security.

No differences were observed for estimated energy intake, the energy distribution from macronutrients, or fiber intake by food security status when stratified by sex (**Table 2**). Regardless of food security status, >75% of boys and of girls exceeded the recommended limits for added sugars and saturated fat, whereas only 1–2% met the AI for fiber. Overall diet quality, as assessed by the total HEI-2015 scores, ranged from 52.1 to 53.7 and did not differ by food security status (**Table 3**). The whole grain HEI component score was significantly lower among food-insecure than food-secure girls, while no other differences in component scores were observed.

When nutrient intakes from food sources alone were examined, food-insecure girls were at higher risk of inadequate intakes (i.e., percentage less than the EAR) for vitamins A, D, and E, calcium, and magnesium compared with food-secure girls (**Table 4**). Compared with food-secure boys, food-insecure boys were at higher risk of inadequate intakes for vitamin E, calcium, and magnesium. Food-insecure boys and girls were less likely to have usual intakes above the AI for choline compared with their food-secure counterparts. Similar patterns were noted when total intakes, inclusive of dietary supplements, were examined. However, after including dietary supplements, the magnitude of the difference in the prevalence of inadequate vitamin D intake by food security status was much larger.

The percentage of those at risk of inadequate intake based on total intake was lower than intake from food sources alone for folate, vitamins C and D, calcium, iron, magnesium, and zinc (Table 4). At the same time, nutrient intakes from dietary supplements increased the risk of potentially excessive intakes (i.e., percentage greater than UL) for folic acid and zinc. For sodium, >90% of boys and girls exceeded the CDRR from intakes from foods alone. The contribution of dietary supplements to total nutrient intakes varied widely: <3% for

TABLE 1 Characteristics of US children aged 1–18 y by sex and food security status, NHANES 2011–2016[1]

Component	Boys		Girls	
	Food secure ($n = 3{,}981$)	Food insecure ($n = 646$)	Food secure ($n = 3{,}940$)	Food insecure ($n = 580$)
Percentage	88.1 ± 0.8	11.9 ± 0.8	89.2 ± 0.8	10.8 ± 0.8
Age group, y				
1–3	16.7 ± 0.8	9.2 ± 1.3*	17.8 ± 0.8	7.3 ± 1.1*
4–8	29.7 ± 1.3	23.7 ± 2.3*	26.5 ± 1.1	24.9 ± 2.4
9–13	25.8 ± 0.8	35.4 ± 3.1*	27.7 ± 1.2	28.9 ± 2.3
14–18	27.7 ± 1.3	31.7 ± 2.3	28.1 ± 1.1	38.9 ± 2.6*
Race and Hispanic origin				
Non-Hispanic white	55.4 ± 3.0	33.6 ± 4.1*	53.5 ± 3.3	39.4 ± 5.6*
Non-Hispanic black	13.0 ± 1.6	23.0 ± 3.1*	13.6 ± 1.7	19.5 ± 2.8*
Hispanic	22.7 ± 2.4	32.9 ± 3.7*	22.5 ± 2.3	34.2 ± 5.2*
Non-Hispanic Asian	4.9 ± 0.6	1.5 ± 0.6*,[2]	5.0 ± 0.5	2.5 ± 0.8*,[2]
Family income level				
PIR ≤1.3	30.8 ± 2.0	61.2 ± 3.9*	32.0 ± 2.5	69.9 ± 4.5*
PIR >1.3–≤1.85	10.9 ± 1.0	17.3 ± 2.6*	12.8 ± 1.2	14.0 ± 2.3
PIR >1.85–≤3.5	27.3 ± 1.6	19.2 ± 3.6*	25.0 ± 1.7	14.5 ± 3.1*
PIR >3.5	31.0 ± 2.2	2.2 ± 0.8*,[2]	30.2 ± 2.4	—*
Household education level[3]				
High school	17.7 ± 1.4	32.7 ± 3.8*	18.6 ± 1.4	32.8 ± 4.3*
High school graduate or equivalent	21.0 ± 1.6	26.5 ± 3.8	19.9 ± 1.3	21.6 ± 2.9
Some college or associate degree	30.9 ± 1.4	30.3 ± 2.9	30.9 ± 1.6	37.5 ± 4.8
College graduate or above	30.4 ± 1.9	10.5 ± 3.1*	30.7 ± 2.3	8.1 ± 1.9*
SNAP participating[4]	25.7 ± 1.8	56.0 ± 4.0*	26.8 ± 2.2	62.9 ± 4.4*
WIC participating[5]	22.2 ± 2.0	36.5 ± 4.9*	23.6 ± 2.2	43.6 ± 5.1*
NSLP/BP participating[6]	44.1 ± 2.6	77.1 ± 2.9*	46.4 ± 3.0	75.5 ± 3.2*
Dietary supplement use	34.8 ± 1.4	21.0 ± 2.8*	35.2 ± 1.6	23.6 ± 3.5*

[1]Values are percentages ± SEs. Percentages may not add up to 100% due to rounding or missing data for some variables. *Significantly different from food-secure group by sex, based on *t*-test, $P < 0.05$. NSLP/BP, National School Lunch Program and Breakfast Program; PIR, family poverty-to-income ratio ($n = 568$ missing); SNAP, Supplemental Nutrition Assistance Program; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children; —, relative SE >40% (data not shown).

[2]The relative SE is >30% but ≤40% and may be statistically unreliable.

[3]Education level of household reference person who owns or rents the residence ($n = 245$ missing).

[4]Household-level participation (SNAP, $n = 24$ missing)

[5]Among children 1–5 y old ($n = 2740$).

[6]Among children 4–18 y ($n = 6618$).

sodium, potassium, choline, calcium, and magnesium; 3–15% for folate, iron, and zinc (all sex and food security subgroups); and >30% for vitamins C and D (only in food-secure girls) (**Supplementary Table 3**).

In general, when stratified by age group, older children were at greater risk of inadequate total nutrient intakes but at less risk of excessive intakes than younger age groups (**Supplementary Table 4**). Nonetheless, among children 1–3 y old, the food-insecure children (74.9%) were at greater risk of inadequate vitamin D intake than the food-secure (65.5%). Adolescent boys and girls (14–18 y old) had the highest prevalence of nutrient inadequacy for the micronutrients examined, compared with other age groups. Food-insecure adolescent girls had a higher risk of vitamin D inadequacy compared with their food-secure peers, but no differences were noted between food-secure and food-insecure adolescent boys (**Table 5**).

Based on biomarkers, no significant differences between food-secure and food-insecure children were observed for vitamin D, zinc, and iron status (**Figure 1**). Among girls 12–18 y, 12.7% of the food-secure and 12.0% of the food-insecure were iron deficient based on total body iron (<0 mg/kg), whereas 21.4% of the food-secure and 14.7% of the food-insecure were iron deficient based on serum ferritin (<15 ng/mL). Among girls 1–18 y, 8.4% of the food-secure and 15.5% of the food-insecure, respectively, had inadequate vitamin D status [i.e., serum 25(OH)D concentrations <40 nmol/L]; the difference was marginally significant ($P = 0.058$). When the cutoff of 25(OH)D <50 nmol/L was used to identify those possibly at risk of insufficiency, food-insecure girls and boys were significantly more likely to have 25(OH)D <50 nmol/L than their food-secure counterparts (**Supplementary Table 5**). Almost no children (aged 1–18 y old) were folate deficient based on serum and red blood cell folate, and very few children aged 1–5 y (<5%) were iron deficient based on either total body iron or serum ferritin, regardless of sex and food security status.

Discussion

Food-insecure and food-secure children as a group had similar energy and macronutrient intakes and HEI-2015 scores, but food-insecure children were at higher risk of inadequacy for some

TABLE 2 Estimated usual intakes of energy and macronutrients from foods alone among US children aged 1–18 y by sex and food security status, NHANES 2011–2016[1]

Component	Boys		Girls	
	Food secure (n = 3981)	Food insecure (n = 646)	Food secure (n = 3940)	Food insecure (n = 580)
Energy, kcal/d	2014 ± 20	2007 ± 53	1684 ± 15	1703 ± 47
Carbohydrate,% kcal	53.2 ± 0.3	53.6 ± 0.7	53.6 ± 0.3	52.7 ± 0.6
Added sugars,[2] % kcal	14.2 ± 0.2	15.1 ± 0.5	14.1 ± 0.3	14.3 ± 0.7
>10% of total energy[2]	81.6 ± 1.5	85.9 ± 3.6	85.5 ± 3.8	76.8 ± 3.7
Total fat, % kcal	33.1 ± 0.2	33.0 ± 0.5	33.4 ± 0.2	33.8 ± 0.5
Saturated fat,[2] % kcal	11.7 ± 0.1	11.3 ± 0.2	11.6 ± 0.1	11.8 ± 0.2
>10% of total energy[2]	82.5 ± 2.0	82.2 ± 5.6	81.7 ± 2.7	90.6 ± 5.2
Protein, % kcal	14.8 ± 0.1	14.7 ± 0.3	14.4 ± 0.1	14.8 ± 0.3
Fiber, g/d	14.8 ± 0.2	15.4 ± 0.5	12.9 ± 0.2	12.5 ± 0.4
>AI, %	1.4 ± 0.3	1.8 ± 0.9[3]	1.1 ± 0.3	—

[1]Values are means ± SEs unless otherwise noted. No significant differences between the food-secure and the food-insecure by sex, based on t-test, $P < 0.05$. AI, adequate intake; —, relative SE > 40% (data not shown).
[2]Only for children aged 2–18 y because the 10% of total recommendations from 2015–2020 Dietary Guidelines for Americans are set for people aged 2 y and older. Food-secure boys (n = 3699), food-insecure boys (n = 620), food-secure girls (n = 3671), and food-insecure girls (n = 567).
[3]The relative SE is > 30% but ≤ 40% and may be statistically unreliable.

micronutrients, even when intakes from dietary supplements were considered, including vitamin D and magnesium among both boys and girls and calcium among girls only. Adolescent girls aged 14–18 y, regardless of food security status, were at greatest risk of micronutrient inadequacy for most nutrients examined, compared with other age and sex groups. Our findings, based on rigorous methods of usual dietary intake estimation and a nationally representative sample of US children, contribute to the evidence that food insecurity is associated with compromised intake of some micronutrients among children and the associations are age and sex specific (11, 15).

Earlier US and Canadian studies have shown that young children's dietary intakes are less likely to be affected by the negative impact of food insecurity than those of adults and adolescents (12, 53). Qualitative studies have suggested that adults may prioritize young children over other household members in terms of food distribution (3). In addition, participation of almost half of infants and one-third of US children 1–5 y in WIC has successfully reduced disparities in dietary intakes among the youngest children (54). Lastly, some fortified foods, such as ready-to-eat cereals, are widely consumed by US children (55), regardless of income, and contribute a range of micronutrient intakes for both food-secure and food-insecure, children including B-vitamins, vitamins C and D, iron, and calcium (56, 57). We found that, with the exceptions of vitamins D and E and potassium, younger children are much more likely to meet the EAR or AI than older children. It should be noted that clinical signs of overt vitamin E deficiency are very rare

TABLE 3 Estimated mean Healthy Eating Index-2015 scores among US children aged 2–18 y by sex and food security status, NHANES 2011–2016[1]

Component (maximum points)	Boys		Girls	
	Food secure (n = 3699)	Food insecure (n = 620)	Food secure (n = 3671)	Food insecure (n = 567)
Total fruits (5)	3.2 ± 0.1	3.2 ± 0.4	3.4 ± 0.1	3.3 ± 0.4
Whole fruits (5)	3.5 ± 0.1	3.4 ± 0.2	3.7 ± 0.1	3.6 ± 0.2
Total vegetables (5)	2.2 ± 0.1	2.7 ± 0.5	2.5 ± 0.1	2.4 ± 0.7
Greens and beans (5)	1.5 ± 0.1	2.5 ± 0.6	1.8 ± 0.1	—
Whole grains (10)	3.1 ± 0.1	2.6 ± 0.4	3.1 ± 0.1	2.5 ± 0.3*
Dairy (10)	8.0 ± 0.1	8.0 ± 0.2	7.9 ± 0.1	8.0 ± 0.4
Total protein foods (5)	4.2 ± 0.1	4.5 ± 0.1	4.2 ± 0.1	4.5 ± 0.2
Seafood and plant proteins (5)	2.7 ± 0.2	3.4 ± 0.5	3.0 ± 0.1	3.0 ± 0.8
Fatty acids (10)	3.1 ± 0.1	3.7 ± 0.6	3.4 ± 0.1	3.1 ± 0.4
Refined grains (10)	4.8 ± 0.1	4.4 ± 0.3	4.9 ± 0.2	4.4 ± 0.4
Sodium (10)	4.7 ± 0.1	4.1 ± 0.4	4.8 ± 0.1	4.4 ± 0.5
Added sugars (10)	6.0 ± 0.1	5.7 ± 0.2	6.1 ± 0.1	5.8 ± 0.5
Saturated fat (10)	5.2 ± 0.1	5.6 ± 0.6	5.1 ± 0.1	4.7 ± 0.9
Total score (100)	52.3 ± 0.6	53.7 ± 1.8	53.7 ± 0.5	52.1 ± 2.5

[1]Values are means ± SEs. Component scores may not add up to 100 due to rounding. *Significantly different from food-secure group by sex, based on t-test, $P < 0.05$. —, relative SE >40% (data not shown).

TABLE 4 Estimated prevalence of usual intakes less than the EAR or above the AI, UL, and CDRR among US children aged 1–18 y by sex and food security status, NHANES 2011–2016[1]

	Boys		Girls	
	Food secure (n = 3981)	Food insecure (n = 646)	Food secure (n = 3940)	Food insecure (n = 580)
Foods alone				
Vitamin A (<EAR)	20.0 ± 1.7	21.0 ± 4.2	24.0 ± 2.0	32.9 ± 3.5*
Folate (<EAR)	—	—	6.0 ± 1.3	11.1 ± 3.1
Vitamin C (<EAR)	17.9 ± 1.8	22.3 ± 2.8	21.8 ± 1.5	25.8 ± 5.5
Vitamin D (<EAR)	88.3 ± 1.3	90.8 ± 2.2	94.8 ± 0.6	97.8 ± 1.1*
Vitamin E (<EAR)	60.6 ± 1.4	74.3 ± 4.4*	72.8 ± 1.4	80.9 ± 3.9*
Calcium (<EAR)	32.0 ± 1.7	42.0 ± 4.5*	52.0 ± 1.4	64.0 ± 4.2*
Iron (<EAR)[2]	2.2 ± 0.3	—	6.2 ± 0.7	6.8 ± 2.0
Magnesium (<EAR)	27.4 ± 1.1	34.9 ± 2.3*	37.4 ± 0.9	50.3 ± 3.0*
Zinc (<EAR)	4.7 ± 1.0	4.7 ± 2.4[3]	13.8 ± 1.9	15.0 ± 3.1
Choline (>AI)	28.1 ± 1.2	19.4 ± 2.2*	18.1 ± 1.1	11.7 ± 2.6*
Potassium (>AI)	38.0 ± 1.6	34.0 ± 4.2	25.0 ± 1.5	20.0 ± 3.9
Folic acid (>UL)	1.7 ± 0.5	—	1.5 ± 0.4	—
Zinc (>UL)	17.3 ± 0.8	11.5 ± 1.7*	14.0 ± 0.7	7.9 ± 1.3*
Sodium (>CDRR)	98.0 ± 0.4	99.0 ± 1.3	93.0 ± 1.3	90.0 ± 4.0
Total				
Folate (<EAR)	—	—	5.0 ± 1.2	9.0 ± 2.9
Vitamin C (<EAR)	15.4 ± 1.5	21.1 ± 2.7	18.0 ± 1.3	23.2 ± 5.4
Vitamin D (<EAR)	71.4 ± 1.3	80.2 ± 2.8*	76.2 ± 1.2	86.8 ± 2.3*
Calcium (<EAR)	31.0 ± 1.6	40.0 ± 4.4	51.0 ± 1.3	63.0 ± 4.2*
Iron (<EAR)[2]	2.1 ± 0.3	—	5.8 ± 0.6	6.6 ± 1.9
Magnesium (<EAR)	26.5 ± 1.0	34.6 ± 2.3*	36.3 ± 0.9	49.5 ± 2.5*
Zinc (<EAR)	4.1 ± 0.9	3.9 ± 2.3[3]	12.4 ± 1.7	14.2 ± 3.0
Choline (>AI)	28.7 ± 1.2	19.7 ± 2.2*	18.6 ± 1.1	12.0 ± 2.5*
Potassium (>AI)	38.0 ± 1.6	34.0 ± 4.2	25.0 ± 1.5	20.0 ± 3.9
Folic acid (>UL)	7.8 ± 0.7	5.3 ± 1.5	6.9 ± 0.8	4.3 ± 1.1*
Zinc (>UL)	21.9 ± 0.8	14.0 ± 1.8*	18.2 ± 0.9	10.1 ± 1.4*
Sodium (>CDRR)	98.0 ± 0.4	99.0 ± 1.3	93.0 ± 1.3	90.0 ± 4.0

[1]Values are percentages ± SEs. *Significantly different from food-secure group by sex, based on *t*-test, $P < 0.05$. AI, adequate intake; CDRR, chronic disease risk reduction intake; EAR, estimated average requirement; NA, not applicable; UL, tolerable upper intake level; —, relative SE >40% (data not shown). Information about supplemental intakes of vitamins A and E is not available in the 2011–2016 NHANES.

[2]Estimated using the probability approach.

[3]The relative SE is >30% but ≤40% and may be statistically unreliable.

despite the high prevalence of inadequate vitamin E intake, and there have been calls for the EAR for vitamin E to be revised (58, 59).

Little evidence is available about the dietary intakes of food-insecure adolescents, but a recent review highlighted adolescence as the life stage where food insecurity may have the largest impact on dietary intakes (11). Critical transitions toward adult dietary patterns occur during this life stage as growth accelerates and sexual maturation occurs, highlighting the importance of meeting dietary recommendations; but adolescents have the poorest diet quality as well as the lowest dietary supplement use among all age groups (60, 61). Even when dietary supplements were considered, we found that adolescents aged 14–18 y were at high risk (>30%) of inadequate intakes for vitamins C and D, calcium, and magnesium. Adolescents were also at high risk of inadequacy for vitamins A and E based on intakes from food sources, and very few (≤5%) had intakes exceeding the AI for choline. These patterns in adolescence may continue into adulthood since the same nutrients were also identified to be under-consumed among adults in a NHANES 2011–2014 analysis of total intakes (48).

Among adolescents, some nutrient recommendations differ by sex. Adolescent girls who are menstruating require more iron to compensate for menstrual losses. Therefore, it is not surprising that the percentage of the population at risk of inadequate iron intake was almost zero in adolescent boys but 16.4% in food-secure and 18.6% in food-insecure adolescent girls. Iron deficiency based on total body iron was also found in 12.7% of food-secure and 12.0% of food-insecure girls aged 12–18 y. Inadequate iron intakes among adolescent girls are of particular concern due to the associated risk of iron deficiency anemia as well as the possible impact on future pregnancy outcomes (62).

Estimated mean HEI-2015 scores were 52–54 out of 100 possible points among children aged 2–18 y, indicating that, regardless of sex and food security status, the overall diet quality of children was poor. The association between food insecurity and diet quality has been weak in previous US studies (12, 15). However, we noted that the HEI-2015 score for the whole grain component was lower in the food-insecure than the food-secure girls, although the difference in boys did not reach statistical significance. Lower intake of whole grains was also noted when

TABLE 5 Estimated prevalence of total usual intakes less than the EAR or above the AI, UL, and CDRR among US adolescents aged 14–18 y by sex and food security status, NHANES 2011–2016[1]

	Boys		Girls	
	Food secure (n = 947)	Food insecure (n = 185)	Food secure (n = 936)	Food insecure (n = 202)
Vitamin A (<EAR)[2]	52.0 ± 2.5	42.0 ± 15.5[4]	49.0 ± 5.3	60.1 ± 8.5
Folate (<EAR)	7.0 ± 2.5[4]	—	19.0 ± 4.9	27.0 ± 5.3
Vitamin C (<EAR)	34.7 ± 9.1	46.3 ± 5.8	45.0 ± 4.0	46.5 ± 8.4
Vitamin D (<EAR)	75.2 ± 2.6	81.0 ± 6.8	83.1 ± 1.8	92.8 ± 3.6*
Vitamin E (<EAR)[2]	78.1 ± 3.8	91.2 ± 5.5	97.3 ± 2.0	95.8 ± 4.2
Calcium (<EAR)	42.0 ± 2.6	45.0 ± 8.7	72.0 ± 2.8	79.0 ± 7.2
Iron (<EAR)[3]	3.3 ± 1.3	0.8 ± 1.4	16.4 ± 2.2	18.6 ± 2.6
Magnesium (<EAR)	67.9 ± 2.4	77.1 ± 5.0	87.4 ± 2.3	88.3 ± 4.5
Zinc (<EAR)	14.7 ± 2.7	6.2 ± 6.2[4]	26.7 ± 4.1	26.3 ± 5.2
Choline (>AI)	5.4 ± 1.8[4]	—	1.1 ± 1.0[4]	—
Potassium (>AI)	32.0 ± 2.8	22.0 ± 5.3	23.0 ± 3.2	24.0 ± 5.7
Folic acid (>UL)	—	—	0.8 ± 0.3[4]	—
Zinc (>UL)	2.0 ± 0.7[4]	—	—	—
Sodium (>CDRR)	96.0 ± 1.5	98.0 ± 2.3	79.0 ± 4.1	87.0 ± 10.5

[1]Values are percentages ± SEs. *Significantly different from food-secure group by sex, based on t-test, $P < 0.05$. AI, adequate intake; CDRR, chronic disease risk reduction intake; EAR, estimated average requirement; NA, not applicable; UL, tolerable upper intake level; —, relative SE >40% (data not shown).
[2]From food sources alone because information about supplemental intakes of vitamins A and E is not available in the 2011–2016 NHANES.
[3]Estimated using the probability approach.
[4]The relative SE is >30% but ≤40% and may be statistically unreliable.

children experiencing very low food security were compared with those with food security in an analysis of NHANES 2007–2010 (63).

Food-insecure children are less likely to take dietary supplements than food-secure children (14). As a result, with vitamin D, for which the contribution of dietary supplements to total intake was substantial (21–42% of total intakes), differences by food security status widened after including dietary supplements. Given that vitamin D intake in childhood influences the development of peak bone mass and that attainment of peak bone mass is directly related to risk of osteoporosis later in life (64), disparities in vitamin D intake in childhood are of public health relevance. We previously reported that differences in the mean adequacy ratio of US children's diets by food security status widened when dietary supplements were included (15). In addition, an earlier study in US adults reported that dietary supplements contributed more micronutrients to total usual nutrient intakes of higher-income than lower-income subgroups (65). However, to our knowledge, no prior studies have assessed total usual nutrient intake distributions by food security status among US children.

This study has strengths and limitations. The strengths include the analysis of data from a nationally representative sample of US children. We combined 6 y of NHANES data to produce reliable estimates; nevertheless, the small sample size of food-insecure children may have contributed to larger SEs and reduced the ability to detect statistical significance. Random measurement error was accounted for by estimating total usual intakes from two 24-h dietary recalls and the frequency-based questionnaire for dietary supplement use using the NCI method. Yet, systematic measurement error that is associated with socioeconomic status remains a potential source of bias in the comparison of food security subgroups (66). However, the extent of reporting bias by food security and its impact on dietary intake estimate is poorly known. In addition, the reporting of dietary intake for children varies by age and may potentially impact our results because data for children ages 1 to 18 y were combined for some analyses. To complement self-reported dietary intake data, we presented available biomarker data. We did not detect differences in the prevalence of suboptimal status of biomarkers for vitamin D, folate, iron, and zinc by food security status. As the concentration of biomarkers examined can be affected by many factors other than dietary intakes, additional studies are warranted. With regard to food security status, we used the most direct measure of food security of children available in the NHANES, but our classification, based on parental report, may not truly reflect children's experiences because their caregivers may not be fully aware of children's perceptions, especially those of older children (2, 67). Future studies may classify food security based on child self-reports and may examine the full range of food security rather than the dichotomized classification presented here. Lastly, the NHANES is a cross-sectional survey, so temporality and causation cannot be inferred from this analysis.

In conclusion, food insecurity was associated with lower intakes of certain micronutrients and whole grains, but not with energy or macronutrient intakes among US children. Among all children, overall diet quality was poor; and sodium, added sugar, and saturated fat intakes were much higher than the recommended limits. The adverse association between food insecurity and children's intakes of some micronutrients is concerning given the importance of childhood for optimal growth and development that can affect life-long health. The constellation of dietary risks in adolescent girls is especially

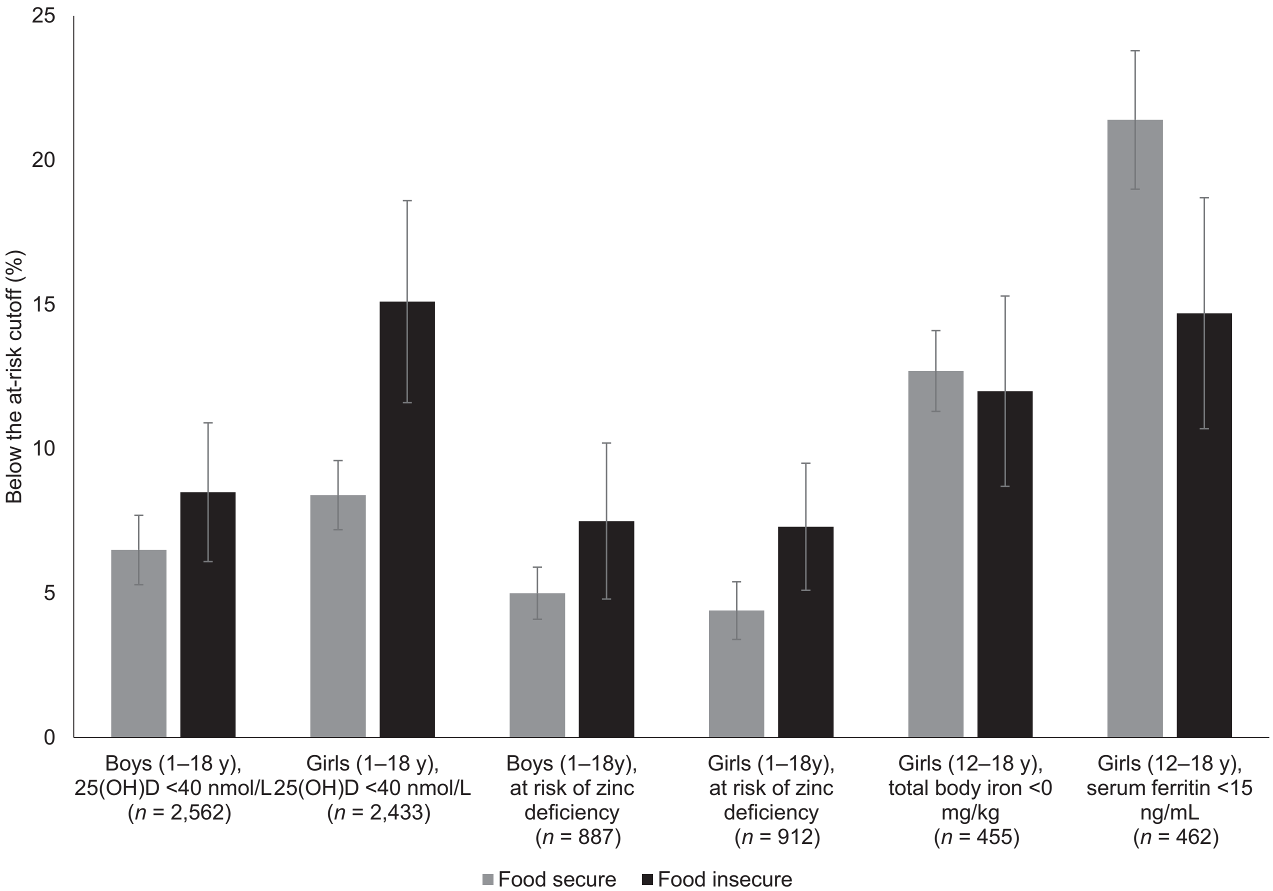

FIGURE 1 Estimated percentage of nutrient biomarker concentrations below the at-risk cutoffs among US children by sex and food security status, NHANES 2011–2016. Values are percentage ± SE. Serum 25(OH)D data were only available in the 2011–2014 NHANES and were adjusted for season (winter and summer). Serum zinc data were limited to the one-third subsample and the cutoffs for assessing the risk of zinc deficiency were as follows: children <10 y (65 μg/dL, morning/nonfasting; 57 μg/dL, afternoon), females aged 10 y and older (70 μg/dL, morning/fasting; 66 μg/dL, morning/fasting; 59 μg/dL, afternoon), and males aged 10 y and older (74 μg/dL, morning/fasting; 70 μg/dL, morning/fasting; 61 μg/dL, afternoon). Serum ferritin and soluble transferrin data were only available for specific sex and age groups in the 2015–2016 NHANES. Iron deficiency based on total body iron was determined as <0 mg/kg. No significant differences between the food-secure and the food-insecure by sex, based on *t*-test, $P < 0.05$. 25(OH)D, 25-hydroxyvitamin D.

alarming. Interventions to improve the availability of and access to nutrient-dense foods are critical to reducing the negative impact of food insecurity on nutrient adequacy among children.

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