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ORIGINAL RESEARCH

Food Insecurity Is Associated With Cardiovascular and All-Cause Mortality Among Adults in the United States

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BACKGROUND: Food insecurity is a global leading public health challenge that affects not only developing countries but also developed countries, including the United States. About 50 million Americans are food insecure. In this study we examined the associations of the adult food insecurity with all-cause and cardiovascular disease mortality in a nationally representative sample of US adults.

METHODS AND RESULTS: We included 27 188 US adults (age ≥40 years of age) who participated in the US National Health and Nutrition Examination Survey from 1999 to 2014. Food insecurity status was assessed using the Food Security Survey Module developed by the US Department of Agriculture. Mortality from all causes and cardovascular disease was ascertained through data linkage to the National Death Index through December 31, 2015. We used multivariable Cox proportional hazards regression with sampling weights to estimate hazard ratios (HRs) and 95% CIs of all-cause and cardiovascular disease mortality, according to food security status. During 205 389 person-years of the period, 5039 deaths occurred, including 1084 cardiovascular disease deaths. After adjustment for age, sex, race/ethnicity, education, income, and dietary and lifestyle factors, participants with very low food security had higher risk of all-cause and cardiovascular disease mortality, with multivariable-adjusted HRs of 1.32 (95% CI, 1.07–1.62), and 1.53 (95% CI, 1.04–2.26), respectively, compared with those with high food security.

CONCLUSIONS: Food insecurity is significantly associated with increased risk of excess death from cardiovascular disease and all causes in US adults.

Key Words: adults ■ all-cause mortality ■ cardiovascular mortality ■ food insecurity

Food insecurity is a condition of limited or uncertain access to adequate food. It has emerged as a major global public health issue that is not only present in developing countries but also in developed countries in Europe and the United States. Food insecurity has been increasing in Europe in recent years.[1] It was estimated that 2.2 million people in the United Kingdom were severely food insecure, according to averaged data from 2015 to 2017.[2] One study showed that, in 2017, ≈19% of children <15 years of age in the United Kingdom were living with an adult who is moderately or severely food insecure, of whom half are severely food insecure.[3] In 1995, when the US Department of Agriculture (USDA) published its first report on household food security in the United States, ≈11.0% of adults indicated household food insecurity.[4,5] Over the past 2 decades, there have been fluctuations yet little overall improvement in the proportion of adults with food insecurity. The most recent report from the USDA estimated that 10.4% of American adults were living in households with food insecurity in 2018.[6]

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CLINICAL PERSPECTIVE

What Is New?

- Food insecurity is associated with higher risk of all-cause and cardiovascular disease mortality among US adults.

What Are the Clinical Implications?

- Our findings highlight the need for continued policy interventions to reduce food insecurity rates and improve public health in the United States.
- Further studies are needed to determine the reasons for the potential adverse health effects of food insecurity and to evaluate the influence of food assistance programs for mitigating food insecurity on long-term risk of adverse health outcomes and mortality.

Nonstandard Abbreviations and Acronyms

CVD	cardiovascular disease
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
USDA	US Department of Agriculture

Despite the high prevalence of the problem, limited evidence is available regarding the impact of food insecurity on mortality. Several studies, mostly cross-sectional, showed that food insecurity is associated with adverse health outcomes, including higher risk of obesity,[7–10] diabetes mellitus,[8,9,11] hypertension,[9,11] hyperlipidemia,[9,11] and cardiovascular disease (CVD),[12] especially among women.[7–10] Because of the negative health consequences found in previous studies, it is not surprising that food insecurity status was found to be associated with higher risk of all-cause mortality in the general population in 2 previous studies.[13,14] Despite studies showing an association between food insecurity and CVD risk and risk factors, no study has addressed the associations of food insecurity status with CVD mortality, which is a major cause of death, although one study did show that food insecurity was associated with a higher risk of coronary heart disease.[12] Other studies on food insecurity and mortality have been done in specific subgroups such as infants[15] or HIV-infected individuals.[16] Given the fact that almost 50 million people in the United States are dealing with food insecurity,[17] and the unclear impact of food insecurity on death,[13] it is important to evaluate the risk of all-cause mortality and the underlying specific causes of mortality related to food insecurity in the general population. Thus, in this study we performed a comprehensive analysis of national data to estimate the public health impact of food insecurity in the United States. We examined the associations of food insecurity with all-cause mortality and CVD mortality in a large, nationally representative sample of US adults.

METHODS

Study Population

The study population consisted of participants from the National Health and Nutrition Examination Survey (NHANES), 1999 to 2014. Briefly, the NHANES is a large-scale, ongoing, nationally representative health survey of the noninstitutionalized US population. It is conducted by the National Center for Health Statistics (NCHS) of the US Centers for Disease Control and Prevention. Since 1999–2000, NHANES surveys have been organized in 2-year cycles; each cycle consists of ≈10 000 participants.[18] Through in-house interviews, NHANES collects a wide range of health-related data to assess diet, nutritional status, general health, disease history, and health behaviors.[18] The surveys use multistage, probability clusters to develop a population sample that is nationally representative of the United States on the basis of age, sex, and race/ethnicity. NHANES data, along with documents on the survey methods and other information, are publicly available on the NHANES web site.[19] All subjects gave written informed consent to participate. The study protocol was approved by the research ethics review board of the NCHS.

For this analysis, we included 27 802 adult participants aged ≥40 years of age and excluded 574 participants who did not complete the food insecurity questionnaire. We then excluded 40 participants who did not have linked mortality information, including underlying causes of death, leaving 27 188 participants in the analysis.

Assessment of Food Insecurity Status

Food insecurity was assessed by the Adult Food Security Survey Module, which is a standardized 10-item questionnaire developed by the USDA, validated, and used in many national surveys.[20] The participants responded to a series of questions about whether there was any food security–related condition or behavior occurring at any time during the previous 12 months, specifying a lack of money and other resources to obtain food as the reason, as described previously by the USDA (Table S1).[6] The series includes 3 questions about food security conditions of the household as a whole, and 7

questions about food security conditions of adults in the household. Voluntary fasting or dieting to lose weight are excluded from the measure. According to the USDA, food-insecure conditions are indicated by responses of "often" or "sometimes" to questions for the household as a whole, and "yes," "almost every month," or "some months but not every month" to questions for the adults. Food insecurity status is determined by the number of food-insecure conditions indicated by the questions. In accordance with the USDA guidance,[6] we classified food security status as high food secure when zero food-insecure conditions are reported; marginal food secure if there are 1 or 2 affirmative responses; low food insecure if there are 3 to 5 affirmative responses; and very low food secure if there are 6 to 10 affirmative responses.

Ascertainment of Mortality Outcomes

Mortality status for each participant was determined using the NHANES Public-Use Linked Mortality File, which was created by the NCHS to permit a longitudinal study of participants in NHANES.[21] This file contains information from results of a probabilistic match between NHANES and the National Death Index records to ascertain the vital status of each eligible NHANES subject through December 31, 2015. The underlying causes of death were classified according to the codes of the *International Classification of Diseases, Tenth Revision* (*ICD-10*). The NCHS classified mortality from heart diseases, including acute rheumatic fever and chronic rheumatic heart diseases (codes I00–I09), hypertensive heart disease (codes I11), hypertensive heart and renal disease (codes I13), ischemic heart diseases (codes I20–I25), and other heart diseases (codes I26–I51), and mortality from cerebrovascular disease (ie, stroke) (codes I60–I69) according to the *ICD-10*. We defined deaths from CVD as death from either heart disease or cerebrovascular disease. People who survived were administratively censored on December 31, 2015. Follow-up time for each person was calculated as the difference between the NHANES survey date and the last known date alive or censored from the NHANES mortality study.

Covariate Assessment

Information on age, sex, race/ethnicity, education, annual household income, smoking status, and physical activity was collected during the in-house interviews.[22] Race/ethnicity was categorized as non-Hispanic white, non-Hispanic black, Hispanic (Mexican and non-Mexican Hispanic), and other race/ethnicity. Educational attainment was grouped as less than high school, high school, and college or higher. Family income-to-poverty ratios were categorized as <1.0, 1.0 to 1.99, 2.0 to 3.99, and ≥4.0, on the basis of federal poverty level for the survey year.[23] Individuals who smoked <100 cigarettes in their lifetime were defined as never smokers; those who had smoked >100 cigarettes but did not smoke at the time of survey were considered former smokers; and those who had smoked >100 cigarettes and smoked cigarettes at the time of survey were current smokers.[24] Dietary intake was assessed through 24-hour dietary recalls. Total energy intake was calculated using a food composition database.[25,26] Alcohol intake was categorized as nondrinking (0 g/d), moderate drinking (0.1–27.9 g/d for men and 0.1–13.9 g/d for women), and heavy drinking (≥28 g/d for men and ≥14 g/d for women).[27] Physical activity was assessed using the Global Physical Activity Questionnaire, and was classified into 3 groups (<600, 600–1199, and ≥1200 metabolic equivalents per minute per week).[28] Overall diet quality was assessed by the Healthy Eating Index 2010, with a higher score indicating a higher overall diet quality.[26] Trained technicians measured weight and height. Body mass index was calculated as weight in kilograms divided by height in meters squared (<25 kg/m^2, 25–29.9 kg/m^2, or ≥30 kg/m^2).

Statistical Analysis

We followed the NHANES analytic guidelines, developed by the NCHS, when conducting and reporting the study data.[23] All statistical analyses accounted for the complex, multistage, stratified, cluster-sampling design of NHANES by using sample weights, strata, and primary sampling units embedded in the NHANES data. Comparisons of characteristics among participants across categories food security status were performed using ANOVA for continuous variables and chi-square test for categorical variables.

We used multivariable Cox proportional hazards regression to estimate hazard ratios (HRs) and 95% CIs of mortality in relation to food insecurity status. In the main model, we adjusted for age, sex, race/ethnicity, education, income, smoking status, alcohol intake, physical activity levels, total energy intake, and Healthy Eating Index 2010 score. We did not adjust for baseline diabetes mellitus, hypertension, hypercholesterolemia, and body mass index status in the main model and only considered adding them into a subsequent model, because these variables may be potential mediators between food insecurity and mortality.[7,9]

To evaluate the potential effect modification, we conducted stratified analyses for the association of food insecurity status with all-cause mortality according to age (40–64 versus ≥65 years old), sex (men versus women),

and race/ethnicity (white versus nonwhite). To further address the possibility of residual confounding, we also adjusted for a propensity score that reflected associations of food insecurity status with the other variables (age, sex, race/ethnicity, education, income, smoking status, alcohol intake, physical activity levels, total energy intake, and Healthy Eating Index 2010 score), as previously mentioned, in the multivariable-adjusted model.[29] All analyses were performed using survey procedures in SAS version 9.4 (SAS Institute, Cary, NC). $P<0.05$ was considered statistically significant.

RESULTS

During 205 389 person-years of the period studied, 5039 deaths occurred, including 1084 CVD deaths.

Table 1. Characteristics of the Study Population (n=27 188) According to Food Security Status

Characteristic	High Food Security	Marginal Food Security	Low Food Security	Very Low Food Security	*P* Value*
No. of participants	21 178	2333	2219	1458	
Age, y	57.4 (0.1)	54.5 (0.4)	53.7 (0.3)	52.5 (0.4)	<0.001
Sex					
Male	47.9 (0.3)	43.0 (1.3)	45.7 (1.2)	44.3 (2.1)	<0.001
Female	52.1 (0.3)	57.0 (1.3)	54.3 (1.2)	55.6 (2.1)	
Race/ethnicity, %					
Non-Hispanic white	78.5 (0.9)	51.8 (2.6)	47.9 (2.7)	54.6 (2.8)	<0.001
Non-Hispanic black	8.7 (0.5)	20.2 (1.5)	19.3 (1.8)	18.6 (1.6)	
Hispanic	7.3 (0.6)	22.4 (2.1)	27.0 (2.2)	20.3 (2.3)	
Other	5.5 (0.3)	5.6 (1.0)	5.8 (0.7)	6.5 (1.0)	
Education, %					
Less than high school	15.9 (0.5)	35.0 (1.6)	42.7 (1.5)	36.5 (1.6)	<0.001
High school	24.1 (0.6)	26.8 (1.3)	24.8 (1.4)	27.6 (1.6)	
College or above	60.0 (0.9)	38.2 (1.8)	32.5 (1.4)	35.9 (1.7)	
Ratio of family income to poverty, %					
<1.0	6.3 (0.3)	26.3 (1.7)	34.4 (1.4)	43.3 (2.1)	<0.001
1.00–1.99	15.2 (0.5)	34.2 (1.7)	36.1 (1.6)	35.3 (2.2)	
2.00–3.99	27.8 (0.6)	25.9 (1.9)	17.6 (1.5)	15.9 (1.8)	
≥4	43.9 (0.9)	7.4 (1.2)	3.7 (0.8)	2.1 (0.9)	
Missing	6.8 (0.3)	6.2 (0.8)	8.2 (1.0)	3.5 (0.6)	
Smoking status, %					
Nonsmoker	50.9 (0.5)	43.6 (1.6)	42.5 (1.6)	37.3 (2.1)	<0.001
Ever smoker	32.2 (0.5)	24.7 (1.4)	23.9 (1.2)	18.4 (1.5)	
Current smoking	16.9 (0.4)	31.7 (1.6)	33.6 (1.5)	44.3 (2.3)	
Alcohol intake†, %					
Nondrinker	64.7 (0.7)	70.5 (1.3)	69.2 (1.6)	73.2 (1.6)	<0.001
Moderate drinking	10.4 (0.3)	6.0 (0.7)	7.6 (0.8)	5.4 (0.9)	
Heavy drinking	16.3 (0.5)	13.6 (1.3)	13.5 (1.1)	13.2 (1.4)	
Missing	8.7 (0.3)	9.9 (1.0)	9.6 (0.9)	8.2 (0.9)	
Physical activity, METs per min/wk					
<600	41.8 (0.7)	50.3 (1.5)	54.9 (1.5)	50.8 (1.6)	<0.001
≥600–1199	13.7 (0.3)	10.7 (0.8)	11.3 (0.9)	8.9 (1.0)	
≥1200	44.5 (0.6)	39.0 (1.5)	33.8 (1.4)	40.2 (1.8)	
Total energy intake, kcal/d	2077 (9.2)	2030 (31.8)	2114 (37.3)	2079 (44.2)	0.83
HEI-2010 score	51.6 (0.2)	46.9 (0.6)	47.3 (0.5)	45.8 (0.5)	<0.001

Data expressed as mean (SE) or percentage (SE) and are weighted except the number of participants. BMI indicates body mass index; HEI-2010, Healthy Eating Index-2010; and MET, metabolic equivalent.

*Comparisons of characteristics among participants across categories food security status were performed using analysis of variance for continuous variables and chi-square test for categorical variables.

†Nondrinker: 0 g/day; moderate drinking: 0.1–27.9 g/d for men and 0.1–13.9 g/d for women; heavy drinking: ≥28 g/day for men and ≥14 g/day for women.

Table 2. Distribution of CVD Risk Factors of the Study Population (n=27 188), According to Food Security Status

CVD Risk Factors	High Food Security	Marginal Food Security	Low Food Security	Very Low Food Security	*P* Value
Baseline diabetes mellitus, %	15.7 (0.4)	21.8 (1.2)	22.4 (1.0)	25.6 (1.4)	<0.001
Fasting glucose* (n=12 141), mg/dL	107.7 (0.5)	111.9 (1.6)	114.5 (1.6)	117.6 (2.6)	<0.001
Baseline hypertension, %	58.2 (0.6)	61.1 (1.2)	60.9 (1.4)	57.2 (1.7)	0.04
SBP (n=24 867), mm Hg	126.6 (0.2)	127.9 (0.6)	126.7 (0.7)	126.8 (0.8)	0.48
DBP (n=24 707), mm Hg	72.3 (0.2)	73.1 (0.3)	73.4 (0.4)	73.9 (0.5)	<0.001
Baseline hypercholesterolemia, %	37.3 (0.5)	36.1 (1.2)	37.1 (1.6)	35.8 (1.7)	0.71
TC (n=24 459), mg/dL	203.7 (0.5)	203.5 (1.2)	205.8 (1.5)	207.0 (2.0)	0.08
LDL-C* (n=11 482), mg/dL	120.1 (0.5)	119.1 (1.7)	120.9 (1.7)	127.0 (2.8)	0.08
HDL-C (n=24 458), mg/dL	54.0 (0.2)	52.1 (0.5)	51.5 (0.5)	51.1 (0.6)	<0.001
TG* (n=12 017), mg/dL	145.9 (2.0)	151.5 (5.0)	155.7 (5.8)	162.2 (9.0)	0.01
BMI categories, %					
Normal weight	26.7 (0.5)	21.5 (1.3)	22.8 (1.3)	23.3 (1.5)	<0.001
Overweight	34.5 (0.5)	32.6 (1.5)	28.5 (1.2)	31.1 (1.8)	
Obesity	33.2 (0.5)	40.8 (1.5)	43.6 (1.5)	40.7 (2.1)	
Missing	5.6 (0.2)	5.0 (0.6)	5.1 (0.7)	4.8 (0.8)	

BMI indicates body mass index; CVD, cardiovascular disease; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; SBP, systolic blood pressure; TC, total cholesterol; and TG, triglycerides.
*Data available only among fasting samples.

As shown in Table 1, participants with low and very low food security were more likely to be younger, have less education and lower family income, be a current smoker, be a non–heavy drinker, and have a lower overall diet quality ($P<0.001$). As shown in Table 2, participants with low and very low food security were more likely to have diabetes mellitus, a higher fasting glucose level, a higher diastolic blood pressure, a lower high-density lipoprotein cholesterol level, and a higher triglyceride level at baseline ($P\leq0.04$).

Food insecurity was associated with higher risk of all-cause and CVD mortality, as shown in Table 3. After adjustment for age, sex, race/ethnicity, socioeconomic status, and lifestyle factors, compared with participants with high food security, participants with marginal food security, low food security, and very low food security had higher risk of all-cause mortality, with multivariable-adjusted HRs (95% CIs) of 1.24 (1.07–1.44), 1.20 (1.04–1.39), and 1.32 (1.07–1.62), respectively. For CVD mortality, participants with marginal food security and very low food security had a higher risk of CVD mortality, with multivariable-adjusted HRs (95% CIs) of 1.34 (1.02–1.77) and 1.53 (1.04–2.26), respectively. These associations were consistent after further adjustment for baseline diabetes mellitus, hypertension, hypercholesterolemia, and body mass index status. Similar results, although the association became even stronger, were observed in a propensity score analysis. The adjusted HRs (95% CIs) were 1.69 (0.94–3.03), 0.94 (0.60–1.49), and 2.56 (1.59–4.10), respectively, for

Table 3. Associations of Marginal, Low and Very Low Food Security With Mortality Among 27 188 US Adults ≥40 Years of Age (NHANES, 1999–2014)

Mortality	High Food Security	Marginal Food Security	Low Food Security	Very Low Food Security
All-cause mortality	4081/21 178	383/2333	354/2219	221/1458
Unadjusted model	Ref	1.30 (1.14–1.48)	1.18 (1.02–1.36)	1.18 (0.97–1.43)
Multivariable adjusted model 1	Ref	1.24 (1.07–1.44)	1.20 (1.04–1.39)	1.32 (1.07–1.62)
Multivariable adjusted model 2	Ref	1.25 (1.07–1.45)	1.20 (1.04–1.39)	1.31 (1.06–1.61)
CVD mortality	859/21 178	94/2333	78/2219	53/1458
Unadjusted model	Ref	1.41 (1.09–1.83)	1.12 (0.84–1.50)	1.37 (0.96–1.95)
Multivariable adjusted model 1	Ref	1.34 (1.02–1.77)	1.13 (0.83–1.54)	1.53 (1.04–2.26)
Multivariable adjusted model 2	Ref	1.32 (0.99–1.75)	1.11 (0.82–1.51)	1.48 (1.02–2.17)

Multivariable adjusted model 1: adjusted for age, sex, race/ethnicity, education, income, smoking status, alcohol intake, physical activity levels, total energy intake, and overall diet quality indicated by Healthy Eating Index 2010 score. Multivariable adjusted model 2: multivariable adjusted model 1 + baseline diabetes mellitus, hypertension, hypercholesterolemia, and body mass index status. CVD indicates cardiovascular disease; NHANES, National Health and Nutrition Examination Survey.

Table 4. Associations of Marginal, Low, and Very Low Food Security With Heart Disease and Cerebrovascular Disease Mortality Among 27 188 US Adults ≥40 Years of Age (NHANES, 1999–2014)

Mortality	High Food Security	Marginal Food Security	Low Food Security	Very Low Food Security
Heart disease mortality	700/21 178	78/2333	63/2219	46/1458
Unadjusted model	Reference	1.52 (1.13–2.04)	1.15 (0.84–1.59)	1.44 (0.97–2.16)
Multivariable adjusted model 1	Reference	1.39 (1.01–1.90)	1.09 (0.78–1.53)	1.49 (0.96–2.32)
Multivariable adjusted model 2	Reference	1.35 (0.98–1.87)	1.07 (0.77–1.50)	1.45 (0.93–2.24)
Stroke mortality	159/21 178	16/2333	158/2219	7/1458
Unadjusted model	Reference	0.92 (0.51–1.65)	0.95 (0.48–1.89)	1.03 (0.39–2.71)
Multivariable adjusted model 1	Reference	1.08 (0.59–1.98)	1.35 (0.63–2.90)	1.76 (0.65–4.77)
Multivariable adjusted model 2	Reference	1.09 (0.58–2.03)	1.37 (0.64–2.92)	1.70 (0.65–4.43)

Multivariable adjusted model 1: adjusted for age, sex, race/ethnicity, education, income, smoking status, alcohol intake, physical activity levels, total energy intake, and overall diet quality indicated by Healthy Eating Index 2010 score. Multivariable adjusted model 2: multivariable adjusted model 1 + baseline diabetes mellitus, hypertension, hypercholesterolemia, and body mass index status.

participants with marginal food security, low food security, and very low food security.

We further examined the association of food insecurity status with heart disease–specific and stroke-specific mortality (Table 4). Compared with participants with high food security, the multivariable-adjusted HRs (95% CIs) of heart disease mortality for participants with marginal food security, low food security, and very low food security were 1.39 (1.01–1.90), 1.09 (0.78–1.53), and 1.49 (0.96–2.32), respectively. For stroke mortality, compared with participants with high food security, the multivariable-adjusted HRs (95% CIs) for participants with marginal food security, low food security, and very low food security were 1.08 (0.59–1.98), 1.35 (0.63–2.90), and 1.76 (0.65–4.77), respectively. These associations were consistent after further adjustment for baseline diabetes mellitus, hypertension, hypercholesterolemia, and body mass index status.

The stratified analyses for the associations of food insecurity with all-cause and CVD mortality are shown in Table S2. Very low food security was associated with higher risk of all-cause and CVD mortality among women or white people, but not men or nonwhite people. In addition, very low food security was associated with higher risk of CVD mortality among people ≥65 years of age but not those <65 years of age.

DISCUSSION

In this large, prospective cohort study in a nationally representative sample of US adults, food insecurity, especially very low food security, was associated with higher risk of all-cause and CVD mortality. The association was independent of potential confounders, including demographics, socioeconomic status, diet, and lifestyle factors.

To our knowledge, this is the first study investigating the associations of adult food insecurity with CVD mortality in addition to all-cause mortality in the general population. These findings corroborate previous findings that food insecurity is associated with a higher prevalence of coronary heart disease.[12] For all-cause mortality, our findings that food insecurity was associated with higher all-cause mortality are generally consistent with previous studies in Canada[14] and the United States.[30]

The mechanisms by which food insecurity is associated with adverse health outcomes and mortality remain to be understood. There are several potential explanations for our findings. First, food insecurity is related to lower socioeconomic status, such as lower income, which has been previously associated with shorter life expectancy.[31] However, the associations remained significant after adjustment for socioeconomic status, including education and income level, which made it less likely that the observed associations were fully due to socioeconomic status. Second, people with lower food security were at risk for less diverse diets of lower quality, such as lower intake of fruits, vegetable, and micronutrients, which have been shown to be associated with higher risk of diet-related diseases such as CVD or diabetes mellitus, and all-cause mortality.[32–35] Nevertheless, it is notable that in our study the results persisted after further adjustment for overall diet quality indicated by Healthy Eating Index 2010, suggesting that the associations of very low food security with mortality could not be fully explained by poor nutrition related to very low food security. The lack of access to nutritious foods among people with very low food security not only affects health through disease occurrence, but also through disease management, particularly among those with diet-related chronic diseases such as CVD and diabetes mellitus. It is more difficult to follow special dietary regimens when there is inadequate food.[9,36] Furthermore, studies have shown that people with very low food security report more difficulty in purchasing prescribed medications and supplies, or filling prescriptions regularly.[37] Medication nonadherence made it much more difficult for

people with very low food security to live with CVD or diabetes mellitus. Finally, a possible mechanism whereby very low food security can influence mortality is through chronic stress, especially in relation to CVD mortality. Food insecurity is a highly stressful condition, both emotionally and physiologically, for a person or household.[38] Periodic episodes of food insecurity and deprivation can lead to eating disorders and stress-related metabolic responses,[2] which can increase the risk of chronic diseases such as CVD.[39,40]

Our study features many strengths. It was based on a nationally representative sample of US adults, the findings of which could be more directly translated to the general population. In addition, food insecurity status was measured using a standardized module developed by the USDA, validated and used in many national surveys.[41] Furthermore, with information on cause-specific mortality, we were able to evaluate risk of death from underlying causes related to food insecurity. Despite these strengths, our study has several limitations. First, food security is a household-level variable, which may not create an equal influence on each adult in the household. Second, despite adjustment for a wide range of potential factors that were both related to food insecurity and mortality, we could not rule out the possibility of residual confounding by unmeasured factors, such as neighborhood characteristics, detailed housing quality, or occupational environment. Third, as in all observational studies, we were unable to establish causal relation between food insecurity and mortality.

Our findings have significant public health implications. Large-scale food assistance programs, such as the Supplemental Nutrition Assistance Program; the Special Supplemental Nutrition Program for Women, Infants, and Children; the National School Lunch Program; and the Emergency Food Assistance Program, have been implemented as a strategy to improve food security across the United States.[42–45] In recent years, there was a gradual reduction in household food insecurity in the United States, but the prevalence was still high, with 10.4% of US households food insecure for at least some portion of 2018.[6] Because of the potential influence of food insecurity on long-term risk of adverse health outcomes, including mortality, continued efforts are needed to combat food insecurity in the United States, especially among those with very low food insecurity. More efforts, such as financial incentives combined with nutrition education[46] and raising Supplemental Nutrition Assistance Program benefits,[47] may also be considered. Further studies are needed to evaluate the influence of food assistance programs on mortality to better understand the potential influence of food insecurity on long-term risk of adverse health outcomes and mortality.

CONCLUSIONS

Our findings show that food insecurity is associated with a higher risk of all-cause and CVD mortality among US adults, independent of other well-established determinants of death, including socioeconomic status. Our findings highlight the need for continued policy interventions to reduce food insecurity rates and improve public health in the United States. Further investigation is needed to determine the impact of food insecurity on global public health and global burden of disease.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Materials

Tables S1–S2

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SUPPLEMENTAL MATERIAL

Table S1. Questions used to assess the adult food security in the U.S. Food Security Survey Module.

Questions about food conditions of the household as a whole
1. "We worried whether our food would run out before we got money to buy more." Was that often, sometimes, or never true for you in the last 12 months?
2. "The food that we bought just didn't last and we didn't have money to get more." Was that often, sometimes, or never true for you in the last 12 months?
3. "We couldn't afford to eat balanced meals." Was that often, sometimes, or never true for you in the last 12 months?
Questions about food conditions of adults in the household
4. In the last 12 months, did you or other adults in the household ever cut the size of your meals or skip meals because there wasn't enough money for food? (Yes/No)
5. (If yes to question 4) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?
6. In the last 12 months, did you ever eat less than you felt you should because there wasn't enough money for food? (Yes/No)
7. In the last 12 months, were you ever hungry, but didn't eat, because there wasn't enough money for food? (Yes/No)
8. In the last 12 months, did you lose weight because there wasn't enough money for food? (Yes/No)
9. In the last 12 months did you or other adults in your household ever not eat for a whole day because there wasn't enough money for food? (Yes/No)
10. (If yes to question 9) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?

Table S2 Stratifeid associations of marginal, low and very low food security and mortality by sex, race/ethnicity and household income among 27,188 U.S. adults aged 40 years or older, NHANES 1999-2014.

	High food security	Marginal food security	Low food security	Very low food security	*P* for interaction
All-cause mortality					
Age					0.003
40-64	Ref	1.25(1.01, 1.57)	1.21(0.97, 1.50)	1.20(0.92, 1.56)	
≥65	Ref	1.16(0.93, 1.45)	1.13(0.94, 1.36)	1.29(0.97, 1.71)	
Sex					0.12
Male	Ref	1.17(0.93, 1.47)	1.22(0.97, 1.53)	1.11(0.84, 1.48)	
Female	Ref	1.30(1.08, 1.58)	1.19(0.96, 1.46)	1.58(1.19, 2.09)	
Race/ethnicity					
White	Ref	1.27(1.02, 1.59)	1.29(1.02, 1.64)	1.47(1.09, 1.99)	0.10
Non-white	Ref	1.14(0.95, 1.36)	1.05(0.87, 1.27)	1.10(0.89, 1.38)	
CVD mortality					
Age					0.99
40-64	Ref	1.48(0.89, 2.48)	0.91(0.55, 1.52)	1.10(0.61, 1.98)	
≥65	Ref	1.16(0.80, 1.67)	1.30(0.87, 1.94)	1.96(1.23, 3.10)	
Sex					0.97
Male	Ref	1.58(1.09, 2.29)	1.17(0.75, 1.82)	1.38(0.74, 2.58)	
Female	Ref	1.01(0.64, 1.59)	1.05(0.60, 1.82)	1.86(1.08, 3.19)	
Race/ethnicity					
White	Ref	1.32(0.86, 2.03)	1.02(0.66, 1.57)	1.73(1.05, 2.86)	0.78
Non-white	Ref	1.27(0.92, 1.76)	1.21(0.77, 1.90)	1.27(0.73, 2.23)	

Based on Multivariable Adjusted Model 1.