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Food Insecurity May Be an Independent Risk Factor Associated with Nonalcoholic Fatty Liver Disease among Low-Income Adults in the United States

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ABSTRACT

Background: Nonalcoholic fatty liver disease (NAFLD), considered a "barometer" of metabolic health, is the leading cause of liver disease in the United States. Despite established associations between food insecurity and obesity, hypertension, and diabetes, little is known about the relation between food insecurity and NAFLD.

Objective: We sought to evaluate the association of food insecurity with NAFLD among low-income adults in the United States.

Methods: We conducted a cross-sectional analysis of a nationally representative sample of adults from the NHANES (2005–2014 waves). Participants included adults in low-income households (≤200% of the federal poverty level) without chronic viral hepatitis or self-reported heavy alcohol use. Food insecurity was measured using the Household Food Security Survey. Our primary outcome was NAFLD, as estimated by the US Fatty Liver Index, and our secondary outcome was advanced fibrosis, as estimated by the NAFLD fibrosis score. The association between food insecurity (defined as low and very low food security) and hepatic outcomes was assessed using multivariable logistic regression, adjusting for sociodemographic factors.

Results: Among 2627 adults included in the analysis, 29% (95% CI: 26%, 32%) were food insecure. The median age was 43 y, 58% were female, and 54% were white. The weighted estimated prevalence of NAFLD did not differ significantly by food security status (food secure 31% compared with food insecure 34%, $P = 0.21$). In the multivariable model, food-insecure adults were more likely to have NAFLD (adjusted OR: 1.38; 95% CI: 1.08, 1.77) and advanced fibrosis (adjusted OR: 2.20; 95% CI: 1.27, 3.82) compared with food-secure adults.

Conclusions: Food insecurity may be independently associated with NAFLD and advanced fibrosis among low-income adults in the United States. Future strategies should assess whether improved food access, quality, and healthy eating habits will decrease the growing burden of NAFLD-associated morbidity and mortality among at-risk adults. *J Nutr* 2020;150:91–98.

Keywords: disparities, nutrition, underserved populations, urban health, food insecurity, vulnerable populations

Introduction

Food insecurity, defined as "a household-level economic and social condition of limited or uncertain access to adequate food" (1), affects more than 12% of US households and 35% of low-income households (2). An emerging body of evidence demonstrates an association between adults living in food-insecure households and increased cardiometabolic risk, including diabetes (3, 4), hypertension (5), obesity (among women) (6, 7), and cardiovascular disease (8).

Nonalcoholic fatty liver disease (NAFLD), considered a hepatic manifestation of metabolic disease, affects 1 in 3 adults in the United States (9). As the fastest growing cause of chronic liver disease, NAFLD will likely be the leading cause of liver transplantation in the United States by 2020 (10, 11). NAFLD represents a wide spectrum of histopathology, from

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simple steatosis (nonalcoholic fatty liver) to nonalcoholic steatohepatitis, which is characterized by steatosis associated with inflammation and, often times, fibrosis. Fibrosis is independently associated with progression to cirrhosis and hepatocellular carcinoma, as well as mortality. It is the most important predictor of adverse outcomes in individuals with NAFLD (11).

Cardiometabolic risk factors are considered key predictors of NAFLD (10), with diabetes and hypertension linked to poor NAFLD outcomes (12–14). Emerging evidence supports a bidirectional relation between NAFLD, diabetes, and hypertension (15). Food insecurity may trigger a complex cycle of poorer dietary intake and compensatory overconsumption of poor-quality foods, predisposing an individual to increased metabolic risk. Furthermore, food insecurity increases household stress, forces trade-offs between food and medical care, increases risk of medication nonadherence, and leads to poorer chronic disease self-management, all important pathways toward worse metabolic and chronic disease outcomes (16, 17).

Despite the reported associations between *1*) food insecurity and cardiometabolic risk and *2*) cardiometabolic risk and NAFLD, no prior studies have examined the association of food insecurity with NAFLD. There are several plausible mechanisms for how food insecurity may heighten risk of fatty liver and progressive fibrosis. Cumulative episodes of diet disruption and hunger may increase systemic inflammation and promote central adiposity, insulin resistance (18), and liver injury (11, 19). Furthermore, changes in diet quality during food-insecure periods may alter gut microbiota (20, 21) and promote hepatic inflammation and scarring (22).

Current individual-level strategies to mitigate the growing NAFLD burden, such as lifestyle change to promote weight loss (11), may be limited in their impact among adults living in low-income households since they may not address upstream, structural drivers of NAFLD (20). Understanding the relation between food insecurity and NAFLD can potentially inform how these structural factors increase risk of NAFLD and subsequently help develop more effective interventions for this at-risk group. We therefore sought to evaluate the association of food insecurity with NAFLD among low-income adults in the United States. We hypothesized that food insecurity would be associated with an increased odds of NAFLD among adults in low-income households.

Methods

Study design and population

We used data from the continuous NHANES from 2005 to 2014. NHANES is a complex multistage, stratified, clustered probability sample representative of the noninstitutionalized population of the United States consisting of cross-sectional interview, examination, and laboratory data (23). For this analysis, participants were included if they were 20 y or older and attended a medical examination at a mobile center and participated in a fasting examination. To restrict our analysis to metabolic liver disease, we excluded participants who had serologic evidence of viral hepatitis infection (i.e., hepatitis B surface antigen, hepatitis C antibody, or hepatitis C viral load), self-reported heavy alcohol use (defined as ≥3 drinks or 36 g of ethanol per day for men, ≥2 drinks or 28 g of ethanol per day for women) (24), or tested positive for pregnancy. We restricted our sample to low-income adults to reduce residual confounding of household wealth. In addition, our primary exposure of food insecurity predominantly affects adults with limited resources. We chose the 200% federal poverty level threshold since individuals living in households reporting >185% federal poverty level have a prevalence of food insecurity of <6% (25). This approach is consistent with other previously cited studies exploring food insecurity and metabolic outcomes that also use the same income poverty threshold (2, 4, 26). The Census Bureau identifies the federal poverty annually based on household income, size, and number of adults and children.

Independent variable

Food insecurity was measured within NHANES using the US Department of Agriculture's Core Food Security Module, which assesses food security status for households using an 18-item questionnaire (1). The module is a widely validated household scale that captures anxiety around food procurement, poor diet quality, and insufficient food quantity over the past 12 mo. Using standard scoring, decreasing numbers of affirmative responses indicate very low, low, marginal, and high food security (27). In our primary analysis, food insecurity was defined as food secure ("high" or "marginal" food security) or food insecure ("low" or "very low" food security) based on official USDA definitions and similar to prior studies linking food insecurity to health outcomes (3, 4).

Dependent variables

Our primary outcome was NAFLD, estimated using the US Fatty Liver Index (USFLI; see **Supplemental Data** for equation). The USFLI was derived in NHANES using ultrasound-assessed NAFLD defined as "mild," "moderate," or "severe." The analysis that derived USFLI combined the "moderate" and "severe" categories to estimate the presence/absence of NAFLD as the outcome (binary), using a cutoff score of ≥30 (9). The index incorporates race/ethnicity, age, waist circumference, and laboratory values for γ-glutamyltransferase, fasting insulin, and fasting glucose.

Our secondary outcome was advanced liver fibrosis, as estimated using the NAFLD Fibrosis Score (NFS; see Supplemental Data for equation). We used a cutoff score of >0.675 for estimating presence of advanced fibrosis based on prior validation studies using biopsy-confirmed advanced fibrosis (28). Biopsy advanced fibrosis has been shown to predict liver-related morbidity and mortality in a similar sample of NHANES patients with NAFLD (29–31). The score uses age, BMI, diabetes/impaired fasting glucose, aspartate aminotransferase, alanine aminotransferase, platelets, and albumin. Both of these noninvasive measures incorporate fasting blood tests to estimate liver disease. The fasting subsample excluded participants if they self-reported taking oral hypoglycemic medications and/or insulin.

Given the overlap of cardiometabolic disease with NAFLD and fibrosis, we also examined the association between food insecurity with diabetes and obesity. We developed a conceptual model based on previous literature that links food insecurity to cardiometabolic risk factors (17, 20) and cardiometabolic risk to NAFLD [(10, 11) see **Supplemental Figure 1**]. Cardiometabolic diseases were defined by both self-report and clinical diagnosis (see **Supplemental Methods**).

Covariates

We included covariates known to be associated with cardiometabolic disease and food insecurity, including sociodemographic factors: age,

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Abbreviations: AOR, adjusted OR; NAFLD, nonalcoholic fatty liver disease; NFS, NAFLD Fibrosis Score; USFLI, US Fatty Liver Index.

sex, race/ethnicity (self-reported non-Hispanic black, non-Hispanic white, Mexican, non-Mexican Hispanic, or other/multiple), household income (<$10,000, $10,000–$19,999, $20,000–$24,999, ≥$25,000), household size, and self-reported educational attainment (less than high school, high school degree, or more than high school degree). Health behavior measurements included daily alcohol intake (any compared with none), smoking consumption (any compared with none), and prior intravenous drug use ("ever use a needle to inject illegal drug") by self-reported questionnaire. We examined if NAFLD and liver fibrosis varied by NHANES survey year and found no change in our model outputs after adjusting for survey cycle.

Statistical analysis

All estimated percentages and ORs were calculated using sampling weights with the survey commands in Stata 15.0 (StataCorp) to properly account for the NHANES complex survey design. We used 10-y examination and fasting weights for mobile examination and self-reported data. We considered P values < 0.05 as significant.

We calculated population-based prevalence estimates using the design-based F statistic. We conducted descriptive analyses of sociodemographic and metabolic characteristics using proportions (%) for categorical variables and means for continuous variables. To examine bivariate associations between categorical or dichotomous variables and liver outcomes, we used the Wald chi-square (χ^2) test adjusting for the complex survey design. We used both unadjusted and multivariable adjusted logistic regression models for each binary outcome (primary: NAFLD; secondary: advanced fibrosis), where the primary independent variable was food insecurity status, controlling for potential confounders: age (per 5 y), sex, household income, household size, education status, race/ethnicity, smoking (current and/or past), and alcohol intake (any). Results are reported as adjusted ORs (AORs) with 95% CIs.

Sensitivity analyses

Recognizing that marginal food security among adults is a risk factor for adverse health outcomes (32), we repeated our analysis with food insecurity categorized by the 4 groups (high, marginal, low, and very low). We then used the margins command in Stata to estimate the model-adjusted predicted prevalence of metabolic outcomes by food security category. To test the robustness of our results in the higher income population, we repeated our analysis including adults from households at all income levels. Since our liver outcome measurement (USFLI and NFS) calculations incorporate cardiometabolic risk factors and thus impede our ability to explore the direct effect of food insecurity with NAFLD with a mediation analysis, we also performed a subgroup analysis assessing the association of food insecurity with NAFLD among adults with diabetes and obesity. Last, we compared estimates by the NAFLD fibrosis score to advanced fibrosis using the aspartate aminotransferase to platelet index ratio index (cutoff ≥0.7 significant fibrosis) (33) and the Fibrosis-4 score (≥3.25 advanced fibrosis) (34) to corroborate our measurement of advanced fibrosis.

Ethics statement

This secondary data analysis did not require institutional review board exemption or approval per the University of California San Francisco Human Research Protection Program. The NHANES surveys are approved by the National Center for Health Statistics ethics board (35).

Results

The 2005–2014 waves of NHANES include 50,965 participants, of whom 13,286 participated in an overnight fasting examination. Among the fasting subsample, 2995 participants met inclusion criteria, of whom 2627 had complete fasting data and were included in the analysis (see **Supplemental Figure 2**). Weighted overall characteristics of the 2627 included in the analysis are summarized in **Table 1**. The estimated prevalence of NAFLD was 32%, and estimated prevalence of advanced fibrosis was 5% among low-income adults. Approximately 1 in 3 adults (29%) lived in food-insecure households. The majority of the sample was female (58%). The median age was 43 y (IQR 30–62), although adults reporting household food insecurity were significantly younger [39 y (IQR 29–53) compared with 46 y (IQR 30–65), $P < 0.01$]. More than 1 in 3 adults (38%) were obese, 13% had diabetes, and 23% had hypertension.

TABLE 1 Weighted population characteristics among adults in low-income households ($n = 2627$)[1]

Characteristic	n	% (95% CI)
Food insecure	795	29 (26, 32)
Liver disease		
NAFLD	911	32 (30, 35)
Advanced fibrosis	173	5 (4, 6)
Demographics		
Age		
20–39 y	1143	51 (48, 54)
40–59 y	737	28 (25, 30)
>60 y	747	22 (20, 24)
Sex (female)	1541	58 (56, 60)
Race/ethnicity		
African American	533	16 (14, 19)
White	1007	54 (48, 59)
Mexican	592	16 (13, 18)
Non-Mexican Hispanic	288	8 (6, 10)
Other[2]	207	7 (5, 9)
Household income		
<$10,000	326	11 (10, 13)
$10,000–$19,999	791	28 (26, 31)
$20,000–$24,999	467	18 (16, 21)
>$25,000	1043	42 (39, 46)
Education		
Less than high school	925	30 (27, 33)
High school	669	26 (24, 28)
More than high school	1033	44 (41, 48)
Behavior		
Current smoking	587	25 (22, 27)
Any smoker	1060	42 (40, 45)
Alcohol[3]	1920	
Light	1670	66 (63, 69)
Moderate	247	10 (9, 11)
Metabolic		
Obesity	1001	38 (36, 40)
Diabetes	418	13 (11, 14)
Hypertension	673	23 (21, 26)

[1] 2005–2014 NHANES fasting subsample (23). Excluded currently pregnant, evidence of chronic hepatitis B virus or hepatitis C virus infection, heavy alcohol consumption, and household income >200% federal poverty line. Subsample by question or examination type: all weights based on examination sampling weight divided by proportion of cycle years (for example, 10 y of data weight constructed by the following equation: WTMEC10YR = 1/5 × WTMEC2YR) (36). NAFLD, nonalcoholic fatty liver disease.

[2] Includes Asian, Pacific Islander, Native American, Alaskan, and other study participants.

[3] Light <1 drink per day; moderate 1–2 drinks per day for women, 1–3 drinks per day for men.

Estimated prevalence of NAFLD and advanced fibrosis by food security status

Comparing food-secure with food-insecure adults, the unadjusted, estimated NAFLD prevalence (food secure 31% compared with food insecure 34%, $P = 0.21$) and unadjusted,

TABLE 2 Association of food insecurity with NAFLD and fibrosis among adults in low-income households (2005–2014 NHANES)[1]

Characteristic	NAFLD ($n = 911$)		Advanced fibrosis ($n = 173$)	
	Crude OR (95% CI)	AOR (95% CI)[2]	Crude OR (95% CI)	AOR (95% CI)[2]
Food insecure (reference: food secure)	1.14 (0.93, 1.40)	1.38 (1.08, 1.77)**	0.91 (0.57, 1.45)	2.20 (1.27, 3.82)**[3]
Age (per 5 y)	1.09 (1.06, 1.13)***	1.14 (1.10, 1.18)***	1.52 (1.45, 1.59)***	1.57 (1.47, 1.68)***
Sex (reference: male)	0.78 (0.64, 0.96)*	0.67 (0.54, 0.83)**	1.49 (1.05, 2.11)*	0.70 (0.48, 1.03)
Race/ethnicity (reference: white)				
African American	0.41 (0.41, 0.56)***	0.42 (0.31, 0.58)***	0.60 (0.38, 0.93)*	1.00 (0.60, 1.67)
Mexican	1.85 (1.40, 1.45)***	2.03 (1.50, 2.74)***	0.59 (0.37, 0.94)**	1.46 (0.78, 2.70)
Non-Mexican Hispanic	0.82 (0.61, 1.11)	0.93 (0.68, 1.27)	0.60 (0.38, 0.93)*	0.32 (0.16, 0.66)*
Other[3]	0.54 (0.35, 0.83)**	0.50 (0.32, 0.77)**	0.37 (0.14, 0.97)*	0.44 (0.16, 1.18)
Household income (reference: ≥$25,000)				
<$10,000	0.88 (0.64, 1.18)	1. 08 (00.76, 1.55)	2.85 (1.57, 5.20)**	2.29 (0.99, 5.32)
$10,000–$19,999	1.02 (0.84, 1.24)	0.99 (0.76, 1.29)	3.57 (1.94, 6.55)***	1.58 (0.77, 3.22)
$20,000–$24,999	0.95 (0.70, 1.29)	0.87 (0.62, 1.20)	2.30 (1.26, 4.18)**	1.31 (0.66, 2.60)
Education (reference: >high school)				
<High school	1.28 (0.99, 1.64)	0.82 (0.62, 1.08)	1.38 (0.85, 2.25)	0.79 (0.43, 1.44)
High school	1.10 (0.84, 1.42)	0.89 (0.67, 1.18)	1.15 (0.70, 1.88)	0.70 (0.40, 1.23)
Any alcohol	0.80 (0.65, 0.98)*	0.83 (0.66, 1.05)	0.36 (0.24, 0.54)***	0.84 (0.49, 1.44)
Any smoker	1.02 (0.86, 1.20)	1.04 (0.84, 1.28)	0.70 (0.48, 1.02)	0.74 (0.46, 1.17)

[1]Fasting subsample ($n = 2627$ fasting examination). P values were generated using multivariable logistic regression, adjusted with the Wald F test. * $P <$ 0.05. ** $P <$ 0.01. *** $P <$ 0.001. AOR, adjusted OR; NAFLD, nonalcoholic fatty liver disease.

[2]Adjusted for age, sex, household income (4 categorical intervals), household size, ethnicity (Mexican, non-Mexican Hispanic, other, white, African American), education (less than high school, high school diploma/GED, greater than high school), and any prior alcohol and smoking history.

[3]Estimates have a relative standard error (RSE) of 35%. RSEs over 30% may not be statistically reliable per NHANES analytic guidelines.

estimated advanced fibrosis prevalence did not significantly differ (food secure 6% compared with food insecure 5%, $P = 0.67$).

Association of food insecurity with odds of estimated NAFLD, advanced fibrosis, and cardiometabolic disease

In models adjusted for demographic, socioeconomic, and behavioral health characteristics (**Table 2**, **Figure 1**), food insecurity was associated with higher odds of estimates of NAFLD (AOR: 1.38; 95% CI: 1.08, 1.77; $P < 0.01$) and advanced fibrosis (AOR: 2.20; 95% CI: 1.27, 3.82; $P < 0.01$) compared with living in a food-secure household. Food insecurity was also associated with higher odds of obesity (AOR: 1.32; 95% CI: 1.06, 1.66; $P < 0.05$), diabetes (AOR: 1.41; 95% CI: 0.999, 1.982; $P = 0.05$), and hypertension (AOR: 1.26; 95% CI: 0.96, 1.65; $P = 0.09$), although the latter association did not reach significance (Figure 1).

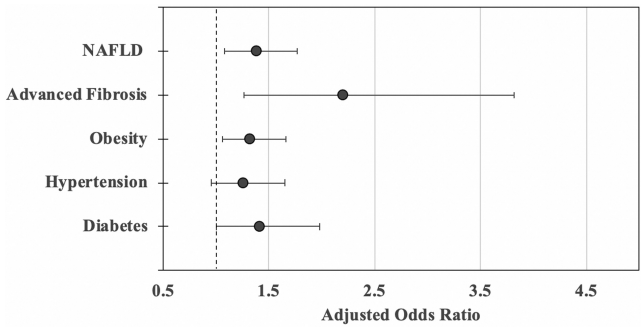

FIGURE 1 Adjusted OR (AOR) of food insecurity with cardiometabolic diseases, nonalcoholic fatty liver disease (NAFLD), and fibrosis among adults in low-income households. Adjusted for age, sex, household income (4 categorical intervals), household size, ethnicity (Mexican, non-Mexican Hispanic, other, white, African American), education (less than high school, high school diploma/GED, greater than high school), and any prior alcohol and smoking history. Includes fasting subsample ($n = 2627$ fasting examination). Error bars represent 95% CI. The dashed reference line reflects an OR of 1.0 (no difference in food insecurity and outcome).

Sensitivity analyses

When food security was examined as a categorical variable, there was a dose-response relation between increasing severity of food insecurity and both NAFLD and advanced fibrosis (**Table 3**). We present the fully adjusted predicted prevalence of obesity, hypertension, diabetes, NAFLD, and advanced fibrosis by food security category (**Figure 2**). The adjusted predicted prevalence of NAFLD among adults in low-income households increased by worsening food security status, approaching nearly 40% among very low food-secure households (30% increase compared to high food-secure households, $P < 0.05$). There was a similar increased adjusted predicted prevalence of advanced fibrosis among very low food-secure households (5% adjusted prevalence, 118% increase compared to high food-secure households, $P < 0.01$).

When we expanded the sample to include all federal poverty levels, the models did not change substantively compared with the original models [$n = 6532$, NAFLD (AOR: 1.36; 95% CI: 1.12, 1.65; $P < 0.01$) and advanced fibrosis (AOR: 2.18; 95% CI: 1.37, 3.47; $P < 0.01$)]. Our model estimates of food insecurity with advanced fibrosis remained significant after limiting our analysis to adults with diabetes [$n = 418$, advanced fibrosis (AOR: 2.40; 95% CI: 1.02, 5.67; $P < 0.05$)] and obesity [$n = 1001$, advanced fibrosis (AOR: 1.97; 95% CI: 1.09, 3.56; $P < 0.05$)]. When we examined the association of food insecurity with advanced fibrosis defined using the aspartate aminotransferase to platelet ratio index, the estimate was similar to when we used the NFS but did not reach statistical significance (AOR: 2.65; 95% CI: 0.97, 7.27; $P = 0.06$; **Supplemental Table 1**).

TABLE 3 Association of food insecurity with NAFLD in sensitivity analysis among adults in low-income households (2005–2014 NHANES)[1]

	NAFLD ($n = 911$)		Advanced fibrosis ($n = 173$)	
Characteristic	*n*	AOR (95% CI)	*n*	AOR (95% CI)[2]
Food insecurity definition				
Low/very low food security (reference: high/marginal)	291	1.38 (1.08, 1.77)**	44	2.20 (1.27, 3.82)**
Food insecurity by category (reference: high)				
Marginal food security	150	1.11 (0.81, 1.52)	15	0.95 (0.51, 1.82)
Low food security	189	1.36 (1.02, 1.83)*	27	1.39 (0.78, 2.51)
Very low food security	102	1.52 (1.05, 2.18)*	17	3.64 (1.53, 8.65)**

[1] Adjusted for age, sex, household income (4 categorical intervals), household size, ethnicity (Mexican, non-Mexican Hispanic, other, white, African American), education (less than high school, high school diploma/GED, greater than high school), and any prior alcohol and smoking history. *P* values were generated using multivariable logistic regression, adjusted with the Wald *F* test. Fasting subsample ($n = 2627$ fasting examination). * $P < 0.05$. ** $P < 0.01$. AOR, adjusted OR; NAFLD, nonalcoholic fatty liver disease.
[2] Estimates have a relative standard error (RSE) of 35%. RSEs over 30% may not be statistically reliable per NHANES analytic guidelines.

Discussion

In this sample of adults in low-income households in the United States, there was an increased association of estimated NAFLD among adults living in food-insecure households, after adjusting for sociodemographic and behavioral factors. The magnitude of association between food insecurity and estimate of advanced liver disease was similar to associations with traditional cardiometabolic diseases, such as obesity and diabetes. These findings suggest that food insecurity may be a contributor to the burgeoning prevalence of metabolic-related liver disease in the United States.

One potential explanation for the observed association between food insecurity and NAFLD is that adults living in food-insecure households have a greater burden of cardiometabolic disease, and subsequent liver disease is mediated by these cardiometabolic risk factors. Prior NHANES analyses found similar associations between food insecurity and diabetes, hypertension, and obesity (2, 4, 5, 7, 8). In addition, we found a "dose-response" relation between severity of food insecurity and NAFLD that mimics similar trends observed in hypertension, diabetes, and obesity (2, 5). Weiser et al. (20) and Seligman and Schillinger (17) offer conceptual models to explain how worsening food insecurity may cause increased cardiometabolic disease. For example, food-insecure adults may have increased rates of obesity due to greater affordability of energy-dense, high-fat foods (37) and an overall decline

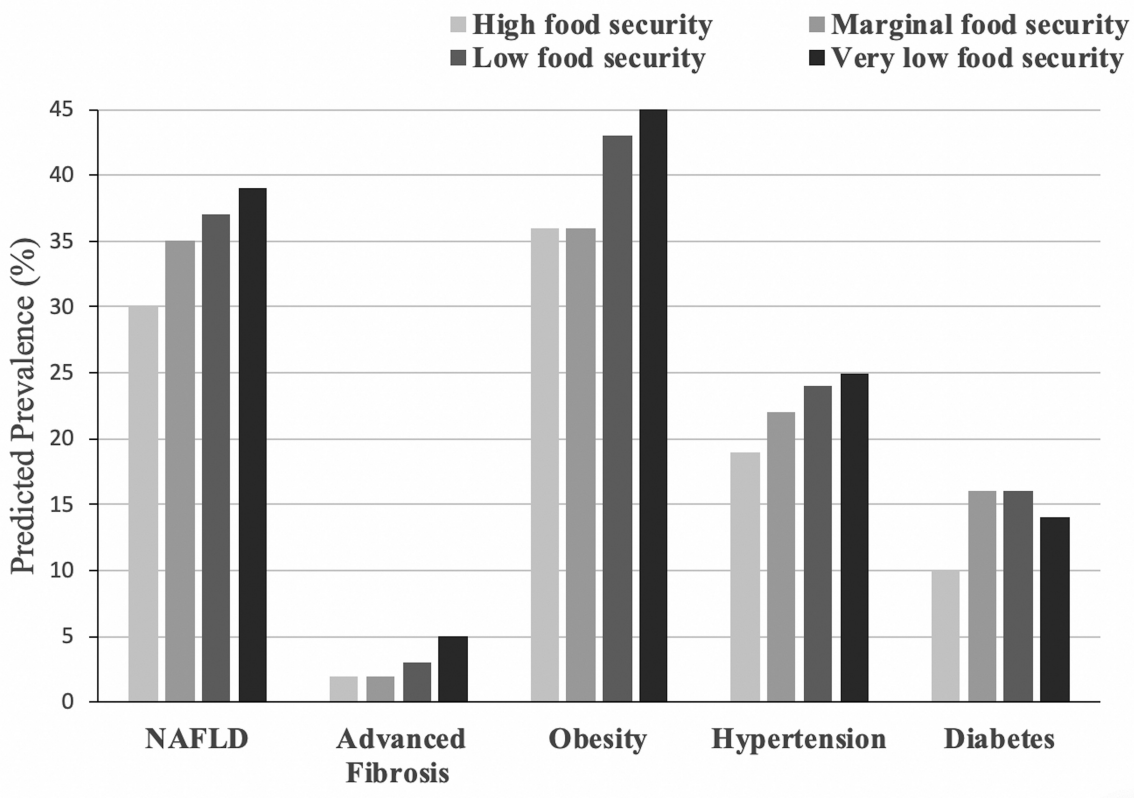

FIGURE 2 Predicted prevalence of cardiometabolic and liver diseases by food security status in adults from low-income households. Adjusted for age, sex, household income (4 categorical intervals), household size, ethnicity (Mexican, non-Mexican Hispanic, other, white, African American), education (less than high school, high school diploma/GED, greater than high school), and any prior alcohol and smoking history. Includes fasting subsample ($n = 2627$ fasting examination). Each darker shaded bar represents worsening food security status. NAFLD, nonalcoholic fatty liver disease.

in dietary quality (38). Food-insecure individuals also have difficulty adhering to their medications and care plans that may be related to financial trade-offs and skipping meals (39). For example, in diabetes, studies have shown that food insecurity is an independent risk factor for poor glycemic control, low self-efficacy (40), and hospitalizations (41, 42). Since NAFLD has traditionally been thought to be a consequence of metabolic disease (11), the increased odds of NAFLD among food-insecure adults may be due to the higher prevalence of metabolic disease among adults in food-insecure households.

Our finding of an increased odds of NAFLD among food insecure adults with diabetes and obesity suggests that food insecurity exacerbates known metabolic risk factors (effect modification) and/or directly drives liver injury (true causal relation). First, insulin resistance may be an evolutionary adaptation to conserve muscle mass during hunger and starvation states, a protective mechanism that may be inappropriately activated during episodes of food inadequacy accompanying food insecurity (3). The resulting hyperinsulinemia can trigger fat breakdown, increasing free fatty acid absorption by hepatocytes and promoting lipotoxicity and inflammation (11, 19). Second, the stress created by inadequate access to food may increase cortisol production and subsequent systemic inflammation (18), creating complex interrelations between central obesity, insulin resistance, and abnormalities in fatty acid metabolism associated with NAFLD (43). Finally, diet quality (high-fat and high-fructose diets) and caloric disruption alter the gut microbiota in ways that could both promote hepatic inflammation and promote gut bacterial translocation that independently drives hepatic injury (20–22, 44–46). These pathways suggest that increased duration and severity of food insecurity may worsen NAFLD outcomes.

An alternate explanation of our findings is that worsened health status (i.e., NAFLD) causes food insecurity, rather than food insecurity causing worsened health status (reverse causality). This "vicious cycle" is well documented in HIV, where illness frequently hampers the ability of the most productive adults to work, drawing resources through caretaking needs and diminishing economic household potential (20, 47, 48). Furthermore, adults living in food-insecure households have significantly greater annual health care expenditures, which may further divert household resources (49). Similar to other metabolic diseases, adults with NAFLD accrue significant medical costs, health care visits (50), and decreased physical function (51) that may diminish their economic productivity and increase their caretaking needs. Longitudinal studies are needed to better understand the temporal associations and directionality between food insecurity and NAFLD.

Whether food insecurity is a cause or a consequence of NAFLD, these findings could have important implications for policy and interventions. Adults with NAFLD, from steatosis to advanced fibrosis, can be screened for food insecurity using validated tools such as the 2-item "Hunger Vital Sign" (52). Targeted interventions to support at-risk adults may attenuate fibrosis progression and offset the annual direct medical costs of over $100 billion attributable to NAFLD in the United States (53). Effective linkage to the Supplemental Nutrition Assistance Program could improve food access and decrease food insecurity (54, 55). Community-partnered programs, such as urban gardens (56) and integrated tailored nutrition and chronic disease programs (57), may both improve and maintain quality dietary intake. Policy strategies, including soda tax (58) and fresh food vouchers (59), may provide the structural backbone to improve access and intake of a nutrient-rich diet among low-income adults with NAFLD.

Our study had several limitations. As a cross-sectional study, we are unable to assess the causal nature of the association between food insecurity and adverse liver outcomes. These liver disease estimates are indirect measures of NAFLD and advanced fibrosis. In addition, our novel use of noninvasive liver measures that incorporate fasting values limited our analysis to adults who participated in the fasting examination. This excluded participants who self-reported oral hypoglycemic medications and/or insulin. Last, our liver outcome measurement (USFLI and NFS) calculations incorporate cardiometabolic risk factors (diabetes, BMI, waist circumference, impaired fasting glucose), and thus we were limited in our ability to conduct a mediation analysis. Furthermore, because age and race/ethnicity are used in calculating the USFLI score, there is by definition an association of these factors with the presence of NAFLD defined using a cutoff value of USFLI. The associations we found therefore cannot be considered to independently corroborate the influence of these factors on risk of NAFLD. We have controlled for them to reduce possible confounding of the other potential risk factors that we have examined, as has been done in previous studies (60–63). As transient elastography monitoring becomes more widespread, improved measurements of NAFLD and advanced fibrosis can help better characterize the relation between food insecurity and liver disease. Despite these limitations, this study is the first large-scale examination of liver disease and its association with food insecurity and suggests an increased burden of NAFLD among food-insecure adults in the United States.

Conclusions

Food insecurity may be independently associated with NAFLD and advanced fibrosis among adults living in low-income households, after adjusting for sociodemographic and behavioral factors. Programs addressing the growing burden of NAFLD-associated morbidity and mortality should consider strategies that improve food access, quality, and healthy eating habits among low-income adults.

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