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A Systematic Review of the Literature on the Relationships between Chronic Diseases and Food Insecurity

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Abstract

Background: The association between food insecurity (FI) and obesity is now so well documented that scholars have dubbed it the "'new' food insecurity" and cited it as a leading cause of increased chronic disease (CD) risk. Here, the chain of causality is assumed to be FI → obesity → CD. However, this model overlooks the possible direct associations between FI and CD independent of obesity. **Aim**: This study assessed the literature on relationships between FI and CD. **Methods**: We conducted a systematic literature review of electronic databases. Selection criteria were designed to elicit studies that assessed FI and CD using a measure of CD other than obesity. **Results**: Fifty-one articles met the inclusion criteria. Forty-five studies (87%) reported a statistically significant association between FI and CD, but only 15 adjusted for obesity. The association was less consistent for asthma and dyslipidemia than for diabetes, hypertension, and other diet-related CDs, and most were conducted in the USA or Canada. **Conclusion**: There is a body of literature documenting relationships between FI and CD, but it is heavily biased toward Western nations, ecological study designs, and type 2 diabetes as the CD of focus. A small subset of the literature controls for BMI, demonstrating that a portion of the FI-CD relationship cannot be fully explained by obesity. Possible direct pathways linking FI and CD include systematic effects of poverty that accompanies FI, micronutrient deficiencies, and environmental exposure to toxins; however, exploration of these alternative pathways is limited by study designs that fail to include obesity as a control variable.

Keywords

Food Insecurity, Chronic Diseases, Systematic Literature Review, Critical Nutrition Studies

1. Introduction

The ecological association between food insecurity (FI) and obesity is now so well documented that scholars have dubbed this pattern the "'new' food insecurity" [1] [2] [3] [4] [5]—an especially challenging public health nutrition problem because it appears to be a bimodal, urban phenomenon encompassing "under- and over-consumption, hunger and obesity, quality and quantity" [2]. Based on the growing literature confirming relationships between food insecurity and obesity, many studies make the understandable assumption that there is a greater risk of chronic diet-related diseases among the food insecure, but they often do so without directly measuring that risk [6]. Even the American Dietetic Association (ADA) now considers food insecurity a risk factor for the development of chronic diseases specifically because of the increased risk of obesity among the food insecure, but this approach overlooks the potential health-demoting effects of FI for health independent of obesity [7] [8].

Several recent literature reviews have attempted to elucidate the relationships between various chronic diseases and food insecurity. They evince a strong focus specifically on diet-related chronic diseases, and, following the ADA's assertion that obesity is a risk factor for chronic diseases, emphasize obesity as the primary mediator that links food insecurity with diet-related chronic diseases [9]-[14]. Very few studies have directly assessed this assumed relationship; rather, most uncritically rely on obesity as a proxy for CD risk, as the ADA now does [8].

Obesity is not, however, a necessary precondition for the development of diet-related or non-diet-related chronic diseases, as the literature from India—one of the world's diabetes capitals—has recently demonstrated [15] [16]. Here, the "thin-fat" phenotype, which occurs when fat is added to an already thin body frame with comparatively low muscle mass, increases metabolic disease risk in the absence of clinical obesity or visible overweight. This is most common among adults born at low birth weight who experienced rapid catch-up growth in childhood [15]. More broadly, literature on early-life adversity demonstrates that experiences of famine in utero or early childhood are related to higher risk for cardiometabolic diseases in adulthood, *even when controlling for obesity* [17] [18] [19] [20] [21].

The characterization in the literature of BMI as a reliable proxy measure for cardiometabolic risk is a problem for two key reasons. First, the flaws of BMI as an indicator of health risk are becoming increasingly clear. BMI is subject to change over the life course, and the physiological risk associated with high BMI can vary quite significantly across populations. Hruschka and Hadley [22], for instance, shows how basal BMI differs dramatically across global populations, leading to the significant misclassification of both under- and overnutrition in many populations. Even among populations for whom BMI works reliably as an indicator of cardiovascular risk, FI-obesity relationship may be inflated when studies rely on self-reported height and weight data, a common practice. Lyons, Park, and Nelson [23] compared self-reported and measured height and weight

and found that only the former demonstrated an association between FI and body mass index (BMI); when measured height and weight were used, the FI-BMI association disappeared. Despite the problems associated with BMI as a measure of disease risk, the assumption that people with high BMI are essentially people with chronic diseases waiting to happen typically goes unchallenged.

Second, the lack of direct assessment of the relationship between food insecurity and chronic diseases is a problem because it overlooks the possible heightened risk of chronic disease among people suffering from food insecurity who are not obese. It also overlooks the many non-lifestyle-related chronic diseases that are influenced by experiences of food insecurity via stress pathways.

Food insecurity is a complex phenomenon whose negative effects extend well beyond dietary quality and quantity. It is related, for instance, to core aspects of wellbeing including immune function, social relationships, and mental health—all of which may exert their own effects on chronic disease processes independently of their association (or lack thereof) with BMI [12] [24]. Therefore the dominant chain of causality, which is assumed to be food insecurity → obesity → chronic disease, may be flawed because the link between obesity and chronic diseases is not always straightforward, and because the link between food insecurity and chronic diseases may be either direct or indirect. As a result, the study of alternate pathways from FI to adverse health outcomes is becoming increasingly of interest [25].

This systematic review is designed to answer the question: What is the state of existing knowledge on the pathways between food insecurity and chronic diseases? In other words, it seeks to avoid over-reliance on obesity as the mediator in the FI → obesity → CD relationship that is present in much of the literature. Instead it focuses on studies that directly assess, or have the potential to assess, the FI → CD relationship.

2. Methods

2.1. Literature Search

The literature search was designed to elicit peer-reviewed articles on the relationships between food insecurity (FI) and chronic diseases (CD), and that employed a measure of CD other than obesity. We conducted a systematic search of Medline, JSTOR, Worldcat, Scopus, Public Affairs Index (PAI), Social Services Abstracts, Annual Reviews Online, and Anthro Source electronic databases. In each database, we conducted a series of searches using an algorithm of all possible combinations of keywords in the following two columns:

Column 1	Column 2
Food insecurity	Chronic disease
Food availability	Noncommunicable disease
Food insufficiency	Chronic fatigue
Food shortage	Fibromyalgia
Food sufficiency	Lupus

Hunger	Obesity
	Disability
	Cardiovascular
	COPD
	Asthma
	Hypertension
	Diabetes
	Dyslipidemia

These keywords were obtained from prior examination of the literature. This list of chronic diseases is by no means exhaustive, but they were selected to represent a range of diet-related, environmental, and idiopathic conditions while still remaining manageable in scope. Search results were sorted first by relevance, and second, by recency of publication; the first 200 results of each search were screened. No specific publication dates were selected for limiting the literature search, but sorting search results by recency and considering only the first 200 results of each search confined our results to articles published during or after the year 2000. Studies were retained for the literature review only if they met the following inclusion/exclusion criteria:

1) Study includes a CD assessment beyond general health self-report, and a FI assessment beyond receiving government-sponsored nutritional benefits or living in an area designated as a "food desert."

2) Article reports on the strength of association or the nature of the relationship between FI and CD.

3) Article is a peer-reviewed original study, published in English or with an abstract in English, and deals with humans (not animal models).

4) Reported CD is not skeletal (e.g., arthritis, osteoporosis), not cancer, nor the result of infectious agents (e.g., HIV/AIDS, cervical cancer caused by the HPV virus). Pre-disease risk states, such as dyslipidemia and insulin resistance, were included.

5) Article does not deal with voluntary food restriction, as in cases of anorexia nervosa, or acute hunger, as in famines.

Potentially relevant articles were downloaded and retained for analysis by the second author; this initial search process resulted in 196 potential articles for inclusion, which were then reviewed by the first author and reduced to 26 articles based on the inclusion and exclusion criteria listed above. To ensure thoroughness, we subsequently performed a cited-reference search ("reverse search") for each article using Google Scholar and reviewed the first 30 results of each search. This resulted in an additional 23 articles fitting the inclusion criteria. Finally, we mined the bibliographies of the retained articles, which led us to an additional 2 meeting the inclusion criteria.

In the qualitative and case-control literature, decisions about the inclusion or exclusion of studies were not always straightforward because assessment of FI or CD was often not quantified or was used as a sample selection criterion rather than a study variable. In such cases, we skimmed results and discussion sections

and included them when they involved explicit discussion of FI-CD relationships.

2.2. Data Extraction

The two authors independently reviewed each article and extracted the following data: study location, design (sample and study type), measure of food insecurity, measure of chronic disease, reported association between the two, control variables used in multivariate analyses (if any), and authors' discussions about the nature of the observed association, or lack thereof. In cases where there were discrepancies in the data extracted from the articles, the first author re-reviewed the article.

3. Results

The final number of articles included in the review was 51. A summary of the studies and their attributes is presented in Table 1, while details of each study are presented in Table 2. They came exclusively from the nutrition, chronic disease, and global health literature.

The 51 studies covered nine countries, with 32 (64 percent) based in the continental U.S., eight (16 percent) in Canada, one (2 percent) in Australia, and the

Table 1. Attributes of the 51 studies included in this literature review.

Year of publication	Number (percent)	Study population	Number (percent)
2000-2006	5 (10)	People with CD	19 (38)
2007-2012	21 (41)	People with FI	1 (2)
2013-2015	24 (47)	General or mixed	31 (62)
Study design		**Chronic disease**	
Cross-sectional	42 (82)	Diabetes	39 (76)
Longitudinal	3 (6)	Hypertension	12 (24)
Case-control	6 (12)	Dyslipidemia	10 (20)
		Asthma	5 (10)
Study setting		Cardiovascular disease	4 (8)
USA	32 (63)	Metabolic syndrome	2 (4)
Canada	8 (16)	Kidney disease	1 (2)
Malaysia	3 (5)		
Iran	2 (4)	**FI Measurement**	
Mexico	1 (2)	HFSSM	39 (76)
Brazil	1 (2)	Other	12 (24)
Jordan	1 (2)		
Kenya	1 (2)	**Main finding**	
Puerto Rico	1 (2)	Positive association-FI & CD	42 (82)
Australia	1 (2)	No positive association	9 (18)

Table 2. Details of the 51 studies included in this literature review.

Study	Sample size	Sample type and composition	Location of study	Study design	Chronic disease measure	Food insecurity measure	Main result
Asaad and Chan 2012	16	convenience, elders 60+ with type 2 diabetes	Canada	Cross-sectional	dietary quality and dietary adherence, knowledge of appropriate diet	HFSSM, slightly adapted	No significant associations between FI and CD.
Azizi *et al.* 2014	260	convenience; all women, half with MetS	Iran	Case-control	Prior diagnosis of Metabolic Syndrome based on the Adult Treatment Pane III	HFSSM	FI significantly associated with metabolic syndrome (OR 3.2; 95% CI 1.9 - 5.6) ($P < 0.05$).
Bawadi *et al.* 2012	843	convenience; adults with type 2 diabetes	Jordan	Cross-sectional	HbA1c	HFSSM, short form	Moderate and severe FI associated with poor glycemic control ($p = 0.04$).
Berkowitz *et al.* 2013	2557	representative; adults with type 1 or 2 diabetes or diabetes meication use from NHANES	USA	Cross-sectional	HbA1c	HFSSM	FI associated with poor glycemic control ($p < 0.001$) and LDL control ($p = 0.002$) after controlling for covariates, but not with BP.
Bhargava *et al.* 2012	903	representative; elders in Georgia (no age specified)	USA	Cross-sectional	Comorbidities numeric count	HFSSM	FI and non-FI adults equally likely to have Medicare and out-of-pocket health expenditures ($p = 0.40$), but expenditures are lower for FI adults ($p < 0.05$).
Chan *et al.* 2015	21	convenience; adults with diagnosed type 1 or 2 diabetes who had experienced FI in previous year	Canada	qualitative cross-sectional	Self-reported diagnosis of type 1 or 2 diabetes by a healthcare professional	3 question instrument derived from HFSSM	People with diabetes report access and preparation barriers to diabetes-friendly foods and social isolation, but also resilience in the face of these challenges.
Chaufan, Davis, and Constantino 2011	21	convenience; Latino immigrants in Northern California	USA	partially qualitative cross-sectional	Self reported	Relying on food aid programs (y/n)	Participants identified type 2 diabetes as the greatest health problem in the community, but uniformly suffered from restricted access to healthy food.
Cheng *et al.* 2013	1733	convenience; people with type 2 diabetes	Kenya	Cross-sectional	HbA1c	HFIAS	High prevalence of FI (68%) among patients with diabetes in a rural, resource-constrained Western Kenyan setting.
Crews *et al.* 2014	10,365	representative; lower-income Americans	USA	Cross-sectional	non-fasting plasma glucose, systolic and diastolic BP, serum and urinary creatinine, urine albumin	HFSSM, slightly adapted	FI related to chronic kidney disease in a dose-response manner among people with type 2 diabetes (OR 1.67, 95% CI 1.14 - 2.45) or hypertension (OR 1.37, 95% CI 1.03 - 1.82).
Cuesta-Briand, Saggers, and McManus 2011	38	convenience; low-income Australians with type 2 diabetes	Australia	qualitative cross-sectional analysis	number of diabetes medications used	Qualitative complaints about dependence on others for food and the high cost of foods	Low-income earners living with diabetes faced food security and reported physical and cost barriers to following a diabetic diet, despite knowing that they should do so.

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de Cássia Ribeiro-Silva *et al.* 2014	1307	convenience; children in public school	Brazil	Cross-sectional	frequency of asthma symptoms (wheezing) in last 12 months	Brazilian Food Insecurity Scale	Asthma severity associated with moderate FI (OR 1.71, 95% CI 1.01 - 2.89) and severe FI (OR 2.51, 95% CI 1.28 - 4.93) in a dose-response manner.
Ding *et al.* 2014	6577	representative; general population	USA	Cross-sectional	HbA1c	HFSSM	Marginally food insecure and food insecure men more likely to have undiagnosed pre-diabetes than food secure men when controlling for covariates (marginal FI OR 1.64, 95% CI 1.12 - 2.38; FI OR 2.12, 95% CI 1.28 - 3.49), but not among women.
Fitzgerald *et al.* 2011	201	convenience; Latina women	USA	Case-control	self-report of diagnosis of diabetes	HFSSM, short form	Individuals with FI more likely to have type 2 diabetes (OR 3.33, 95% CI 1.34 - 8.23).
Ford 2013	10,455	representative	USA	Cross-sectional	HbA1c, CRP, and cotinine; systolic BP, total cholesterol and HDL/LDL cholesterol	HFSSM	Severely FI adults had elevated HbA1c ($p = 0.006$), CRP ($p = 0.02$), and cotinine ($p < 0.001$), but not BP or cholesterol. Severely FI adults had increased predicted 10-year cardiovascular disease risk (adjusted prevalence ratio 2.38, 95% CI 1.31 - 4.31).
Galesloot *et al.* 2012	314	convenience; Canadian adults with diagnosed type 1 or 2 diabetes	Canada	Partially qualitative cross-sectional	previous diagnosis with diabetes mellitus and attending counseling sessions	HFSSM	Higher rate of FI among individuals with diabetes in active care than among a general population sample ($p < 0.001$).
Gucciardi *et al.* 2009	2523	representative; Canadians with diabetes	Canada	Cross-sectional	diabetes medication use, plus self-report of diagnoses from physicians of: diabetes, hypertension, heart disease, stroke, and glaucoma	HFSSM	FI more prevalent among individuals with diabetes (9.3%, OR 8.2 - 10.4) versus without diabetes (6.8%, 95% CI 6.5 - 7.0), and associated with several indices of poor diabetes management, mental health problems, and poor quality of life.
Hanson and Olson 2012	225	representative; rural low-income adults	USA	longitudinal	being in the upper quartile of Chronic Health Conditions Index	HFSSM	Despite strong knowledge of community resources and usage of food aid programs, FI was common (occurring in 65% at some point over the 3-year study period). Enduring chronic health problems greatly increased the risk of persistent FI (OR 7.01, $p < 0.01$), and education beyond high school was the only factor protective against persistent FI ($p < 0.05$).

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Hasan-Ghomi *et al.* 2015	400	adults with and without type 2 diabetes	Iran	Case-control	fasting plasma glucose	HFSSM	No significant differences in FI risk between diabetic and nondiabetic groups. Women were at higher risk of FI regardless of diabetes status (nondiabetic OR 3.2, 95 CI 1.3 - 7.7; diabetic OR 2.4, 95% CI 1.02 - 5.5).
Heerman *et al.* 2016	401	representative; adults with diabetes	USA	Cross-sectional	HbA1c	3 question instrument derived from HFSSM	FI is common in low-SES people with type 2 diabetes (73%); FI associated with lower adherence to self-care recommendations ($p = 0.002$ - 0.03 for various recommendations) and worse glycemic control ($p = 0.03$).
Hendrickson *et al.* 2010	127	convenience; families presenting to a hospital for child asthma	USA	Cross-sectional	frequency of coughing or wheezing, night cough, activity limitation, missed school days, return to ED, length of hospitalization	HFSSM	FI is common in families of asthmatic children (35%), but is not associated with indicators of asthma severity.
Holben and Pheley 2006	808	convenience; rural adults	USA	Cross-sectional	diastolic BP, total cholesterol, random blood glucose, HbA1c, hemoglobin	HFSSM	BMI ($p = 0.04$) and obesity ($p < 0.001$) were higher among people with FI, but diastolic BP, total cholesterol, random blood glucose, HbA1c, and hemoglobin did not differ.
Homenko *et al.* 2010	74	representative; rural older adults with type 2 diabetes (age not specified)	USA	Cross-sectional	HbA1c	HFSSM, short form	FI associated with higher BMI ($p = 0.01$) but not HbA1c.
Hwang and Bugeja 2000	50	convenience; homeless in Toronto	Canada	partially qualitative, cross-sectional	HbA1c	"difficulties obtaining the necessities of life" scale derived from qualitative interviews	Homeless adults with diabetes reported difficulties managing their disease, and poor glycemic control was common (44%). However, people rarely said that poor glycemic control created difficulties obtaining the necessities of life.
Kollannoor-Samuel *et al.* 2012	211	convenience; Latinos in US with type 2 diabetes	USA	Partially qualitative cross-sectional	fasting blood glucose, HbA1c	HFSSM	FI associated with experiencing barriers to diabetes self-care (ORs ranging 1.22 - 1.46, 95% CIs ranging 1.04 - 1.82)
Liu *et al.* 2015	5533	representative; adults without diabetes	USA	Cross-sectional	fasting plasma insulin and glucose	HFSSM	FI related to insulin resistance among normal weightmen after controlling for covariates (OR 3.99, 95% CI 1.71 - 9.33). Among women, association was significant in bivariate analysis only ($p < 0.001$ overweight; $p = 0.001$ normal weight).

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Lyles *et al.* 2013	665	representative; low-income adults with type 2 diabetes	USA	longitudinal	HbA1c	HFSSM	FI associated with higher HbA1c, lower self-efficacy, and lower consumption of fruits and veg (all $p < 0.05$); but after an educational intervention, these differences disappeared.
Mangini *et al.* 2015	11,099	representative; American third-graders	USA	Cross-sectional	parental report of child's asthma diagnosis	HFSSM	Household FI associated with child asthma regardless of race/ethnicity (OR 1.04; 95% CI 1.02 - 1.06), but to different degrees between ethnic groups.
Marjerrison *et al.* 2011	183	convenience; families of children with type 1 diabetes	Canada	Partially qualitative cross-sectional	HbA1c	HFSSM	Children from FI households have higher HbA1c ($p = 0.039$) and more frequent hospitalizations ($p = 0.002$), but only in bivariate analyses.
Mayer *et al.* 2016	407	convenience; adults on Medicaid or living in a zip code with high poverty, with diabetes	USA	Cross-sectional	HbA1c	HFSSM	FI associated with poor glucose control (OR 2.23, 95% CI 1.22 - 4.1), while SNAP enrollment was associated with lower risk of poor glucose control (OR 0.27, 95% CI 0.09 - 0.08).
Mohamadpour, Sharif, and Keysami 2012	169	representative; Malaysian Indian women	Malaysia	Cross-sectional	BP, lipids, plasma glucose	Radimer/ Cornell Hunger and Food Insecurity Instrument	No significant differences in total cholesterol, triglycerides, HDL, LDL, plasma glucose, or blood pressure by FI status.
Moreno *et al.* 2015	250	convenience; Latinos with diabetes	USA	Cross-sectional	LDL cholesterol, BP, HbA1c	HFSSM	People with type 2 diabetes and FI reported more medication underuse (OR 2.49, 95% CI 1.30 - 4.98; $p = 0.003$), poorer diabetes control (OR 0.24; 95% CI 0.07 - 0.84; $p < 0.05$), and fewer preventative exams (both $p < 0.05$) than those without FI.
Nelson *et al.* 2001	1503	representative; adults with diabetes	USA	Cross-sectional	self-reported health status, number of physician encounters, and number of hospitalizations	HFSSM	FI was associated with fair or poor self-reported health status in bivariate analysis ($p = 0.05$) but not multivariate. In both bivariate and multivariate analysis, FI diabetics reported higher healthcare utilization ($p = 0.05$).
Nur Atiqah *et al.* 2015	124	convenience; young adults at university	Malaysia	Cross-sectional	Lipid profile, CRP, and body composition	Adult Food Security Survey Module	No significant associations between FI and CD.
Parker *et al.* 2010	9251	representative; general population	USA	Cross-sectional	total cholesterol, HDL cholesterol, BP, blood glucose, BMI	HFSSM	Adults with marginal or severe FI more likely to have MetS (marginal OR 1.80, 95% CI 1.30 - 2.49, severe OR 1.65, 95% CI 1.12 - 2.42), but not adolescents.

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Pérez-Escamilla *et al.* 2014	32320	representative; general population	Mexico	Case-control	self-reported doctor diagnoses of diabetes or hypertension	Modified version of the Latin American and Caribbean Food Security Scale	FI was a risk factor for type 2 diabetes among women ($p = 0.005$) but not men ($p = 0.349$), and for hypertension across genders (women $p = 0.037$, men $p = 0.072$).
Sattler and Bhargava 2016	2944	representative; adolescents only	USA	Cross-sectional	fasting plasma glucose and 2 hour plasma glucose following an OGTT, total cholesterol, BP, HbA1c	HFSSM	FI not associated with glucose, cholesterol, BP, or HbA1c in bivariate analyses.
Sattler and Lee 2013	664	convenience; older Americans enrolled or waitlisted for Older Americans Act Nutrition Program	USA	longitudinal	Blood glucose, total cholesterol, BP, healthy diet, BMI, smoking, and physical activity	HFSSM	People with persistent FI over the 8-month period were more likely to report being diagnosed with coronary heart disease and diabetes, and to practice cost-related medication nonadherence (all $p < 0.05$).
Seligman *et al.* 2007	4423	representative; general population	USA	Cross-sectional	self report and fasting serum glucose	HFSSM	Diabetes prevalence was higher in severely FI groups after adjusting for sociodemographics, physical activity level, and BMI (OR 2.1, 95% CI 1.1 - 4.0, $p = 0.02$).
Seligman *et al.* 2010	40	convenience; low-income adults with type 2 diabetes	USA	Cross-sectional	HbA1c	HFSSM, short form	FI was associated with inadequate diabetes control (OR 1.35, 95% CI 1.05 - 1.7), and average HbA1c was higher, though not statistically significant.
Seligman *et al.* 2012	711	convenience; people with type 2 diabetes in safety net health clinics	USA	Cross-sectional	HbA1c	HFSSM	FI is an independent risk factor for poor glycemic control (OR 1.48, 95% CI 1.07 - 2.04), possibly through the mechanisms of difficulty following a diabetic diet, and emotional distress stemming from low diabetes self-efficacy.
Shariff *et al.* 2014	625	representative; women only	Malaysia	Cross-sectional	fasting serum glucose, lipid profile, BP	Radimer/ Cornell Hunger and Food Insecurity Instrument	Women in FI households were less likely to have elevated glucose, high total cholesterol or LDL (all $p < 0.05$), when controlling for sociodemographic covariates.
Sharkey 2003	279	representative; homebound older women receiving meal delivery services	USA	Case-control	self-reported doctor diagnosis of 9 diseases, plus effect of disease(s) on daily activities	4 question instrument derived from elements of food insecurity reported among elders in a previous study	Women with FI were more likely to report multimorbidity than those without FI (OR 3.69, 95% CI 1.14 - 12.0, $p < 0.001$).

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Shin *et al.* 2015	1663	representative; adults	USA	Cross-sectional	serum lipid levels: total cholesterol, LDL, and HDL	2 question instrument derived from the Behavioral Risk Factor Surveillance System and NHANES	FI not associated with total cholesterol. FI associated with low HDL among women only (OR 2.31, 95% CI 1.42 - 3.76), but not men.
Shiue 2016	4979	representative; general population	USA	Cross-sectional	BP, serum glucose, total cholesterol and HDL, CRP	HFSSM	FI associated with prior asthma ($p = 0.002$), arthritis ($p = 0.051$), chronic bronchitis ($p = 0.001$), depression ($p < 0.001$), diabetes ($p = 0.042$), eczema ($p = 0.001$), emphysema ($p = 0.013$), liver problems ($p = 0.022$), suggesting disability from illness might prevent these individuals from being employed.
Silverman *et al.* 2015	287	convenience; US adults with poorly controlled type 2 diabetes	USA	Cross-sectional	HbA1c	HFSSM	FI associated with depression ($p < 0.001$), diabetes distress ($p < 0.001$), low medication adherence ($p = 0.02$), and worse glycemic control ($p = 0.02$).
Tarasuk *et al.* 2013	77,053	representative; general population	Canada	Case-control	self report of physician diagnosis of 10 conditions	HFSSM	Most conditions increased the odds of FI when controlling for other sociodemographics, and this effect became greater with the increasing number of comorbid chronic conditions: OR 1.43, 95% CI 1.28 - 1.59 for one condition, OR 1.86, 95% CI 1.62 - 2.14 for two, and OR 3.44, 95% CI 3.02 - 3.93) for 3 or more.
Tayie and Zizza 2009	5549	representative; general population	USA	Cross-sectional	serum fasting triglyceride, total cholesterol, LDL, HDL, and their ratios	HFSSM	FI not associated with lipid measures among men. Among women, those with moderate food insecurity were more likely to have abnormal LDL ($p = 0.045$), and those with FI but not hunger had higher abnormal fasting serum triglyceride ($p = 0.041$).
Terrell, Drew, and Vargas 2009	15,199	representative; general population	USA	Cross-sectional	HbA1c, BP, proteinuria	HFSSM	People with FI were more likely to have diabetes based on self-report (OR 1.45, 95% CI 1.13 - 1.85). People with FI and hypertension were more likely to have better blood pressure control (OR 1.335, 95% CI 1.06 - 1.68).

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Vozoris and Tarasuk 2002	210,377	representative; general population	Canada	Cross-sectional	Functional health index, self report of doctor diagnosis of heart disease, diabetes, high BP, and food allergies	3 question instrument derived from HFSSM	People from FI households were significantly likelier to report having heart disease (OR 2.5, 95% CI 1.6 - 3.8), diabetes OR 1.8, 95% CI 1.2 - 2.6), or hypertension (OR 1.6, 95% CI 1.2 - 2.1), and greater odds of reporting poor health (OR 2.9, 95% CI 2.4 - 3.4), multiple chronic conditions (OR 2.8, 95% CI 2.3-3.4), and depression (OR 3.5, 95% CI 2.9 - 4.4).
Weigel *et al.* 2007	100	convenience; migrant farmworkers in USA	USA	Cross-sectional	self report of 16 health conditions, plus BP, lipid profile, blood glucose, BMI, and waist circumfe-rence	HFSSM	FI households were more likely to have at least one member affected by self-reported symptoms of *deprimido* (OR 6.0, 95% CI 1.28 - 27.6), *nervios* (OR 2.71, 95% CI 1.19 - 6.18), or physician-diagnosed learning disorders (p = 0.031). No physical measures of CD were associated with FI.
Weinreb *et al.* 2002	408	representative; homeless mothers and their children	USA	Cross-sectional	adapted version of the National Health Interview Survey, Child Health Supplement	adapted version of the Childhood Hunger Identification Project Measure	Children with moderate or severe hunger had more chronic illnesses after controlling for covariates (p = 0.05).

remaining 9 (18 percent) in the following lower- and middle-income countries: Puerto Rico, Malaysia, Iran, Jordan, Kenya, Mexico and Brazil. Among the 9 studies reporting no association between FI and CD were all 3 studies conducted in Malaysia, suggesting that there may not be a FI-CD relationship in that particular locale as compared to the other 8 countries represented in the sample [26] [27] [28].

Sampling and study design varied widely. The vast majority of studies were quantitative (45 studies; 90 percent) and cross-sectional (43 studies; 86 percent) in their design. Six studies (12 percent) were partially or entirely qualitative, 3 studies (5 percent) were longitudinal, and 5 studies (10 percent) were case-control studies. The average sample size was 8,397 (range 16 - 210,377). Twenty-three studies (46 percent) used convenience samples, while 28 (56 percent) used representative samples, many of which were drawn from large national data sets such as the USA's National Health and Nutrition Examination Survey (NHANES). Nineteen studies (38 percent) recruited participants with CDs already diagnosed, while only 1 study (2 percent) examined CD outcomes among people already identified as FI. The remaining 31 studies (62 percent) examined associations between FI and CD in general samples or those selected

on a demographic indicator, such as being low-income or being of a specific race or ethnicity. Six studies (12 percent) used women-only samples, and no studies used men-only samples. Minority race/ethnicity and older age were two other common demographic factors on which samples were selected, presumably because these are considered risk factors for FI and/or CD.

The studies largely reported positive relationships between FI and CD. That is, most (42 studies; 82 percent) reported that as FI increased, so did CD prevalence or severity, or the reverse: as CD severity increased, so did FI. The remaining 9 studies (18 percent) reported no positive association between FI and CD [26]-[34].

The strength and consistency of relationships between FI and CD varied depending on the CD under consideration. The studies reporting on type 1 or 2 diabetes, hypertension, heart disease, the Metabolic Syndrome, and chronic kidney disease found positive associations between FI and CD. There was marked inconsistency, however, in studies dealing with asthma and dyslipidemia. Five of the 10 studies dealing with dyslipidemia reported either no positive relationship, or a positive relationship between FI and dyslipidemia on only some (not all) indicators or in only some portions of their study samples. For instance, Tayie and Zizza's [35] study of a representative sample of US adults reported an association between FI and dyslipidemia, but only for some levels of FI, only among women, and only on some markers of dyslipidemia and not others. Also somewhat inconsistent was the relationship between FI and asthma. While five studies dealt with asthma, only three reported measures of asthma severity, and one of those three found no association between household FI and any of their asthma severity indicators [30].

Only 15 of the total of 51 studies addressing FI-CD relationships controlled for BMI, waist circumference, or another measure of obesity in their multivariate analyses [36]-[50]. With one exception [41], those that did so uniformly documented an association between FI and the CD of interest-which in these cases were type 2 diabetes, asthma, and dyslipidemia-even when controlling for BMI.

The studies reported some differences in the FI-CD relationship along demographic lines. Lower socioeconomic status was the most common predictor of a positive relationship between FI and CD, and many of the studies specifically worked with low-income populations. Minority race/ethnicity, older age, and female gender were also significant demographic predictors of FI-CD relationships, but, as noted above, many of the studies that addressed these variables selected their samples on one or more of these characteristics and therefore lacked a comparison group.

4. Discussion

The 51 studies included in this literature review confirm a positive relationship between food insecurity (FI) and chronic diseases (CD), and they suggest some possible mechanisms explaining that association. However, only 15 studies controlled for body mass index (BMI) in their statistical analyses, a technique that allows researchers to determine if there is elevated risk of chronic diseases

among people with food insecurity independent of obesity. This is important because, as noted in the introduction, BMI is not always a reliable indicator of cardiometabolic risk; moreover, studies that rely on BMI as a proxy indicator of CD risk fail to include subgroups of people with FI who are not obese but may nevertheless be at increased risk of CD because of the systemic harm created by the profoundly stressful experience of FI.

4.1. Food Insecurity and Chronic Disease Associations Independent of Obesity

The 15 studies included in the literature review that controlled for BMI in their analyses consistently reported associations between FI and CD risk independent of obesity. Seligman *et al.* [48], for instance, found that in a nationally representative sample of Americans, food insecurity was independently associated with diabetes. Although obesity among women was also associated with mild food insecurity, obesity accounted for only 20% of the increased odds of diabetes. Importantly, these studies indicate that a significant portion of the FI-CD relationship cannot be explained by obesity. We therefore urge researchers to include direct measures of CD risk biomarkers (such as high-sensitivity C-reactive protein assay for cardiometabolic risk, or lung function for asthma severity) along with BMI. Moreover, we underscore the need for biopsychosocial studies integrating qualitative work, biomarkers for CD and risk status, and standardized measures of FI to identify some of the apparent sources of association between FI and CD independent of obesity. This appears to be important both for diet-related and non-diet-related CD; among the studies demonstrating relationships between CD and food insecurity independent of obesity were both those focusing on diet-related diseases such as type 2 diabetes, and those focusing on non-diet-related diseases such as asthma.

These 15 studies are in the minority; little of the FI-CD research is designed to include statistical tests of the presence or absence of a mediating role for obesity in the FI-CD association. To correct for this, we recommend that even if researchers adopt more direct measures of cardiometabolic risk in their studies, they still include BMI as a control variable to assess the portion of the FI-CD relationship not accounted for by BMI.

4.2. Possible Mechanisms of the FI-CD Association

Many studies documented a FI-CD relationship without speculating about its causes, and those that did so almost universally addressed causes as theoretical possibilities rather than performing statistical tests to identify potential mediators. As a whole, the studies suggested three main categories of mediators. Each is summarized below.

The first, and most common, pathway that researchers proposed to link FI and CD is a broad category that we refer to as "economic mechanisms". In households with economic constraints, FI is more likely, as are a suite of other stressors that may interact cyclically with health to produce CD risk even when

obesity is not present. As Crews *et al.* [38] and Tarasuk *et al.* [51] noted, unemployment related to chronic illness disability may be an important economic driver the CD-FI association. In such cases, the high cost of CD medications may leave insufficient money for nutritious food, and a lack of nutritious food exacerbates many CDs even in the absence of obesity, leading to higher treatment costs, medication nonadherence, and increased FI, in a cyclical relationship [36] [37]. Some of the work included here demonstrates that poverty leads to both FI and reduced healthcare usage (including medication nonadherence) [52] [53].

The six studies that included qualitative data also underscored the relevance of economic mechanisms linking FI and CDs. These studies demonstrated that low-income people with type 2 diabetes struggled to adhere to diabetic diets because of economic constraints including limited household finances, geographic unavailability of healthy foods, and lack of control over their own diets, rather than because of lack of awareness about the importance of dietary control [54] [55] [56]. These studies particularly highlighted the diabetes-inappropriate food available at food banks and the fact that dependence on food aid constrains one's ability to choose what to eat [32].

The wide range of pathways falling under the economic explanation attests to a social reality: that food insecurity rarely occurs in isolation; rather, it is only one of many physical, mental, and social health problems that households face when dealing with economic constraints. The studies that assessed psychological, social, and health outcomes found that FI is only one of many variables associated with CD risk among marginalized groups; other important CD predictors were depression and poor social support; culturally specific distress, gastrointestinal infection, low maternal education, and child learning disorders; and homelessness, stressful life events, low birthweight, and parental anxiety [34] [57] [58]. Food insecurity is both an index and an engine of poverty, and poverty is one of the most systematically health-harming forces to which humans can be exposed [59].

A second pathway potentially linking FI and CD in the absence of obesity is cyclically dysregulated eating patterns among FI individuals, such as reduced intake during food shortage followed by overconsumption when food is available, which leads to metabolic disruption that can lead to metabolic diseases even when a person is not obese [28] [40] [48] [60]. The eating disorder literature has long demonstrated that cyclical food restriction and bingeing interferes with normal metabolism via dysregulation of the HPA axis, which in turn appears to be related to visceral fat deposition (a strong risk factor for many chronic diseases) [61] [62] [63]. There is a parallel body of literature suggesting direct relationships between FI and dysregulated eating patterns [64] [65]. Food assistance programs might play a role in dysregulated eating because they emphasize processed foods and typically disburse benefits once monthly, thus leading to monthly cycles of feast-and-famine [1] [4] [66] [67]. Dysregulated eating behaviors—potentially perpetuated by reliance on once-monthly food aid or food

banks—may predispose individuals to chronic diseases via metabolic dysregulation without the necessary precondition of obesity.

A third possible pathway linking FI and CD in the absence of obesity is high exposure to environmental toxins among people suffering from FI. Sattler and Bhargava [33], for instance, note the greater likelihood of smoking in low-income households as a potential risk factor for CDs independent of obesity. Along the same lines, Shiue [68] points out that people suffering from FI are also more likely to be exposed to high levels of environmental contaminants known to induce chronic diseases, such as bisphenol-a (BPA; an endocrine disrupter), pesticides (also endocrine disrupters), and antimony (a chemical element linked to liver dysfunction).

Strikingly few of the studies included in this review discussed biosocial pathways that might connect FI and CDs, such as the psychoneuroimmunological connections between distress and chronic health problems. Mangini *et al.* [45] make a nod to the whole-person approach to understanding FI-CD risk, pointing out that the associations between household poverty and child asthma must be understood within the framework of a life course model of health disparities. Pérez-Escamilla *et al.* [47] similarly point out that the chronic stress of FI could lead to higher stress hormones such as cortisol, which promotes abdominal fat storage, leading to type 2 diabetes and hypertension. None of these studies, however, considers the possibility that stress activation could lead to these CDs independently of the mechanism of abdominal fat storage-for instance, through generalized inflammation, which has been shown to be a strong predictor of chronic disease even when controlling for socioeconomic and dietary variables [69].

4.3. Gaps in the Literature

The literature was generally biased toward cross-sectional, quantitative studies based in North America. More longitudinal and qualitative studies are needed, as are studies conducted in low- and middle-income countries. Several studies emphasized the unique challenges faced by women, but work is needed on the qualitative and quantitative associations between FI and CD in men specifically, since men may experience FI and CD differently than women both physiologically and psychologically. Moreover, because studies addressing asthma and dyslipidemia were, as a whole, inconclusive about their relationships with FI, more work is needed on these potential relationships. No studies addressing chronic fatigue syndrome, fibromyalgia, lupus, or COPD were found during the review process. This may seem logical, given the widespread assumption that non-lifestyle-related diseases are less likely to be affected by food insecurity than are those directly related to diet or lifestyle. However, studies demonstrating clear links between food insecurity, stress response, and body inflammation suggest, at very least, that there is a potential link between non-diet-related diseases and food insecurity [69]. This warrants further exploration.

Further study is also needed to determine if there are differences in the FI-CD relationship in low- and middle-income settings as opposed to industrialized countries; the three studies in Malaysia documented no association between FI and CD, suggesting that this relationship may work differently in less-developed economies. Likewise, further work on the role of gender, minority race/ethnicity, and age with relevant comparison groups would help elucidate how these demographic characteristics may shape the FI-CD relationship.

Finally, the large proportion of studies publishing positive results could be of concern. While it is entirely plausible that this reflects a secular association between CD and FI, it could also reflect publication bias toward positive study results. We therefore encourage researchers who find no positive association between CD and FI to seek publication.

4.4. Limitations

This review was not designed to include the literature on the associations between health behaviors and food insecurity, which is substantial. The review also did not include studies conducted among populations with HIV/AIDS, which under treatment with regular antiretroviral drugs becomes very much like a chronic disease. There is significant literature, however, exploring relationships between FI and HIV/AIDS.

5. Conclusions

Food insecurity (FI) and chronic diseases (CD) are often related, as this literature review demonstrated. Moreover, there is evidence to suggest that FI and CD may be associated with one another independent of obesity, which is often assumed to be the variable mediating this association. Based on the literature reviewed here, other possible mediators of the FI-CD relationship include the effects of limited finances on health behaviors and treatment adherence (and vice-versa), micronutrient deficiencies that might lead to CDs in the absence of obesity, and exposure to environmental toxins leading to CDs. Few studies considered the potential direct effects of psychosocial stress resulting from systematic social and economic exclusion on CD risk, of which FI may be just one manifestation.

Because the evidence is limited, the present study concludes that more research is needed on the possible direct pathways linking FI and CDs without the reliance on obesity as the key explanatory variable mediating this relationship. Moreover, inclusion of mixed-method and longitudinal studies would be useful to help identify the mechanisms implicated in FI-CD relationships. Studies in low- and middle-income countries and studies that deal with non-diet-related CDs such as asthma, lupus, and fibromyalgia are also needed to correct for gaps in the literature. We caution researchers to avoid relying on BMI as a proxy for chronic disease risk or as an explanatory variable in studies of the FI-CD relationship, but instead to employ direct measures of CD risk and use BMI as a

control variable. Finally, we encourage those finding no positive relationship between FI and CD to seek publication of their results in order to correct for potential publication bias.

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Conflict of Interest

None declared.

Consent for Publication

Weaver and Fasel give consent for the manuscript in its present form to be reviewed for publication.

Ethical Approval

Since this was a systematic literature review, no ethical approval was required.

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