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Household food insecurity is associated with diabetic ketoacidosis but not severe hypoglycemia or glycemic control in youth and young adults with youth-onset type 2 diabetes

Lauren A. Reid[1] | Jason A. Mendoza[2,3,4] | Anwar T. Merchant[1] | Marco Geraci[1,5] | Beth A. Reboussin[6] | Faisal S. Malik[2,3] | Alice M. Ellyson[2,3] | Dana Dabelea[7] | Lina Merjaneh[2,3] | Santica M. Marcovina[3] | Eva Lustigova[3] | Jean M. Lawrence[8] | Angela D. Liese[1]

[1]Department of Epidemiology and Biostatistics, University of South Carolina, Columbia, South Carolina, USA

[2]Center for Child Health, Behavior and Development, Seattle Children's Research Institute, Seattle, Washington, USA

[3]Department of Pediatrics, University of Washington, Seattle, Washington, USA

[4]Fred Hutchinson Cancer Research Center, Seattle, Washington, USA

[5]School of Economics, Sapienza University of Rome, Rome, Italy

[6]Department of Biostatistics and Data Sciences, Wake Forest School of Medicine, Winston Salem, North Carolina, USA

[7]Department of Epidemiology, University of Colorado School of Medicine, Aurora, Colorado, USA

[8]Division of Epidemiologic Research, Department of Research & Evaluation, Kaiser Permanente Southern California, Pasadena, California, USA

Correspondence
Angela D. Liese, Department of Epidemiology and Biostatistics, Arnold School of Public Health, University of South Carolina, 915 Greene Street, Room 417, Columbia, SC 29208, USA.
Email: liese@mailbox.sc.edu

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Abstract

Objective: To examine the association between household food insecurity (HFI), glycemic control, severe hypoglycemia and diabetic ketoacidosis (DKA) among youth and young adults (YYA) with youth-onset type 2 diabetes.

Research design and methods: This cross-sectional study included 395 YYA with type 2 diabetes from the SEARCH for Diabetes in Youth Study (2015–2019). HFI was reported by young adult participants or parents of minor participants via the US Household Food Security Survey Module. Glycemic control was assessed by HbA_{1c} and analyzed as a continuous and categorical variable (optimal: <7.0%, suboptimal: ≥7.0%–9.0%, poor: >9.0%). Acute complications included self-reported severe hypoglycemia or DKA in the last 12 months. Adjusted logistic and linear regression were used for binary and continuous outcomes, respectively.

Results: Approximately 31% reported HFI in the past 12 months. Mean HbA_{1c} among those with HFI was 9.2% compared to 9.5% without HFI. Of those with HFI, 56% had an HbA_{1c} >9.0% compared to 55% without HFI. Adjusted models showed no associations between HFI and glycemic control. Of those with HFI, 14.4% reported experiencing DKA and 4.7% reported severe hypoglycemia. YYA with HFI had 3.08

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times (95% CI: 1.18–8.06) the odds of experiencing DKA as those without HFI. There was no association between HFI and severe hypoglycemia.

Conclusions: HFI was associated with markedly increased odds of DKA but not with glycemic control or severe hypoglycemia. Future research among YYA with type 2 diabetes should evaluate longitudinally whether alleviating HFI reduces DKA.

KEYWORDS

diabetic ketoacidosis, food insecurity, glycemic control, hypoglycemia, type 2 diabetes

1 | INTRODUCTION

Household food insecurity (HFI) is the "limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways."[1] In 2020, 11% of U.S. households were food insecure at least some time during the year. Additionally, between 2019 and 2020, HFI increased for households with children from 14% to 15%.[2] Food insecurity is particularly prevalent among households where someone has a cardiometabolic disease. We recently reported that more than 30% of youth and young adults (YYA) with type 2 diabetes experience HFI[3]—substantially higher than YYA with type 1 diabetes (18%)[3] and the 2020 national average of 11% of households.[2]

The SEARCH for Diabetes in Youth Study has recently reported rising incidence and prevalence of type 2 diabetes in youth (<20 years) and young adults (<36 years), particularly in racial and ethnic minority groups. Between 2002 and 2015, the incidence of type 2 diabetes increased at a rate of 4.8% (95% CI: 3.7–5.92) per year and increased for all race and ethnic groups except non-Hispanic whites.[4] From 2001 to 2017, the prevalence of type 2 diabetes increased from 0.3 per 1000 to 0.7 per 1000, representing a 95% increase.[5] These trends suggest that an increasing number of YYAs, many with HFI, will be burdened with type 2 diabetes.

The etiology of type 2 diabetes in YYA is not completely understood but social determinants of health seem to play an important role,[6] with low socioeconomic status (SES) a common demographic attribute.[6,7] HFI is one potentially modifiable attribute associated with being in a low SES household. Among older adults with type 2 diabetes, there is substantial evidence for a relationship between HFI, poor glycemic control,[8–13] and hypoglycemia.[14–16] Additionally, a recent cross-sectional study reported an association between HFI and glycemic control among YYA with type 1 diabetes.[17]

The majority of YYA with type 2 diabetes are not meeting recommended glycemic targets with only 35% attaining the HbA_{1c} goal of <7.0%.[18] Moreover, compared to non-Hispanic white YYA, higher percentages of non-Hispanic black and Hispanic YYA with type 2 diabetes do not meet glycemic control recommendations.[13,19] When diabetes is not properly managed, diabetic ketoacidosis (DKA) and severe hypoglycemia are two common acute complications that can occur in people with diabetes.[20] Poor diabetes management is of particular concern for YYA with type 2 diabetes because they have a higher risk of developing chronic complications, including nephropathy, retinopathy, and peripheral neuropathy than YYA with type 1 diabetes.[21] Moreover, YYA with type 2 diabetes are typically overweight or obese and therefore prone to secondary comorbidities including hypertension, hyperlipidemia, non-alcoholic fatty liver disease, and cardiovascular disease.[22]

To date, no studies have examined the association between glycemic control and HFI in YYA with type 2 diabetes. In addition, few studies have examined the relationship between HFI and acute diabetes complications such as DKA and severe hypoglycemia in any population. The purpose of this study is to examine the association between HFI and glycemic control and acute complications of diabetes (DKA and severe hypoglycemia) among YYA with youth-onset type 2 diabetes. We hypothesize that HFI will be associated with higher $HbA_{1c,}$ poor glycemic control, and higher odds of experiencing DKA or severe hypoglycemia in the last 12 months.

2 | RESEARCH DESIGN AND METHODS

We utilized data from the SEARCH for Diabetes in Youth Study (SEARCH) to conduct a cross-sectional analysis. SEARCH comprises a surveillance effort assessing incidence and prevalence of youth-onset type 1 or type 2 diabetes and, built on the surveillance effort, a longitudinal multi-site cohort study.[23,24] The aim of the cohort study is to advance the understanding of the epidemiology of non-gestational diabetes among YYA who were diagnosed with diabetes before 20 years old.[23,24] An in-depth synopsis of the methods used in SEARCH have been published elsewhere.[23] Briefly, SEARCH Phase 1 began in 2001 with prevalent diabetes cases and added incident cases in 2002–2005. SEARCH Phase 2 included surveillance efforts for incident diabetes cases in 2006 and 2008; and, participants enrolled in Phase 1 were invited to re-enroll.[23] SEARCH Phase 3 (funded period 2010–2015) recruited persons with incident cases between 2010 and 2015. It also created the SEARCH cohort by inviting participants from Phases 1 and 2 to another in-person visit if they (1) had a diagnosis date between 2002 and 2005, 2006, or 2008, (2) completed a baseline in-person visit, and (3) had at least 5 years of diabetes duration at the time of the visit. The SEARCH Phase 4 Cohort study (funding period 2015–2020)

includes eligible participants from SEARCH 3. It was divided into 2 groups: 1) those invited to another in-person study visit, and 2) those who were only invited to complete surveys. Participants invited to the in-person visit included all those with type 2 diabetes, all those with type 1 diabetes who did not identify as non-Hispanic White, and a random sample of those with type 1 who identified as non-Hispanic white; all were 10 years or older. Participants that were diagnosed in 2012 and participated in the SEARCH 3 registry in-person visit were also invited to the in-person visit in SEARCH 4.

The current study focuses on YYA with provider diagnosed type 2 diabetes ($n = 395$) and data collected during phase 4 of SEARCH (between 2015 and 2019). Institutional Review Board approval was granted at each of the five participating centers in five locations (South Carolina, Ohio, Colorado, California, and Washington) before data collection began. Adult participants provided informed consent to participate in the study. Parents/guardians of participants younger than 18 years provided informed consent, and the youth provided assent.

2.1 | Household food insecurity

HFI was measured with the18-item United States Household Food Security Survey Module.[25] This instrument measures HFI over the previous 12 months by having respondents affirm statements and questions regarding having enough money for food and is used in national surveys and in research studies.[1] The first 10 items pertain to all households (with or without children) and the last eight items are specific to households with children ages 0–17.[1] The first two items of the Household Food Security Survey Module, ("(I/We) worried whether (my/our) food would run out before (I/we) got money to buy more," and "The food that (I/we) bought just didn't last, and (I/we) didn't have money to get more"), are routinely used as screening questions in clinical care.[26,27]A review of 24 food security measures indicates the United States Household Food Security Survey Module is a robust, valid, and reliable (Cronbach's alpha = 0.86–0.93) measurement tool.[1,28,29] The validity for differentiating households was established in Frongillo et al.[30]

Parents/guardians of SEARCH youth participants (<18 years of age) and participants 18 years of age or older completed the survey. Households were classified as food insecure if the respondent affirmed ≥3 food insecure conditions or behaviors.[25] A continuous scaled score[1] that ranges from 0 to 9.3, with a higher score indicating increased HFI, was also used in the analysis.

2.2 | HbA_{1c} and glycemic control

HbA_{1c} was measured in a sample of whole blood taken from participants during an in-person visit and analyzed with an automated non-porous ion-exchange high-performance liquid chromatography system (model G-7; Tosoh Bioscience, Montgomeryville, Pennsylvania).[19] Samples were processed in the Northwest Lipid Metabolism and Diabetes Research Laboratories in Seattle, WA.[17] Glycemic control was categorized as follows: HbA_{1c} <7.0% is optimal, 7.0%–9.0% is suboptimal, and >9.0% is poor.[20,31]

2.3 | Acute complications of diabetes

Information about DKA and severe hypoglycemia episodes were collected via a survey. The question pertaining to DKA states "In the last 12 months, have you (has your child) had diabetic ketoacidosis (often called DKA, frequently with high blood sugar, vomiting and shortness of breath)?" The question pertaining to hypoglycemia states "In the last 12 months, have you (has your child) had any severe hypoglycemia, that is, very low blood sugar that required you to get help?" Response categories for each question were "yes," "no," or "don't know."

For the analysis, "don't know" answers were set to missing. Binary variables were created that dichotomized responses into having DKA or severe hypoglycemia the last 12 months or not.

2.4 | Covariates

The participant's age and diabetes duration were analyzed as continuous variables. Categorical variables included sex (female, male), race and ethnicity (Hispanic, Non-Hispanic Black, Non-Hispanic White Other races), SEARCH clinic site (South Carolina, Colorado, Ohio, California, Washington), highest parental education (Less than high school graduate, High school graduate, Some college / Associate degree, Bachelor's degree or more), household income (<$25,000, $25,000–49,999, $50,000–74,999, $75,000+), insurance type (private/exchanges, state/federal, other/unknown, none), diabetes medication regimen (Insulin pump, Insulin long-acting 3+ rapid acting injections, Any other combo of insulin injections, oral hypoglycemic medication, no treatment) and continuous glucose monitoring use (yes/no).

2.5 | Description of the sample size

The fourth phase of SEARCH included 395 YYA with youth-onset type 2 diabetes. Household income, parent education, and insurance status were the most frequently missing demographic variables [$n = 146$ (37.0%), $n = 35$ (8.9%), and $n = 15$ (3.8%), respectively]. Given that SEARCH is a 20-year longitudinal study and includes 3–6 prior data collection points for each participant, we explored and confirmed that that these three variables were relatively stable over time. Thus, for participants with household income, parent education, or health insurance status missing at SEARCH Phase 4, we substituted the value with the most recently available timepoint.

We conducted a sensitivity analysis to compare results from the adjusted models with and without inclusion of the household income variable. The results of the analysis with income included in the model are in Tables S1 and S2. The rationale was that despite the substitution approach outlined above, 55 income values were still missing from the assessment of HFI and HbA_{1c} models and 59 values were missing from the assessment of HFI and DKA, and 59 values were missing from the assessment of HFI and severe hypoglycemia. Without restricting the dataset to those that had income, the analysis for the association between HFI, HbA1c and glycemic control yielded 326 participants, the analysis for the

TABLE 1 Demographic characteristics of 326 youth and young adults with youth-onset type 2 diabetes: the SEARCH for Diabetes in Youth Study Phase 4

Characteristic	Total	Food secure ($n = 224$)	Food insecure ($n = 102$)
Continuous HFI score	1.7 (2.1)	0.4 (0.7)	4.4 (1.5)
Age in years, mean (SD)	24.7 (4.3)	24.5 (4.4)	25.2 (4.1)
Sex, %			
Female	67.5	65.2	72.6
Male	32.5	34.8	27.5
Race and ethnicity, %			
Hispanic	25.2	27.7	19.6
Non-Hispanic Black	44.2	45.5	41.2
Non-Hispanic White	19.3	16.1	26.5
Other[a]	11.4	10.7	12.8
Clinic, %			
Carolinas	33.4	32.1	36.3
Ohio	17.8	18.3	16.7
Colorado	22.1	21.0	24.5
California	21.2	25.0	12.8
Washington	5.5	3.6	9.8
Parent education, %			
<High school graduate	12.0	12.1	11.8
High school graduate	34.4	35.7	31.4
Some college—Associate's degree	37.7	36.2	41.2
Bachelor's degree +	16.0	16.1	15.7
Insurance status			
State/federal	37.7	35.7	42.2
Private/exchanges	43.6	46.0	38.2
None	14.4	13.8	15.7
Other/unknown	4.3	4.5	3.9
Diabetes duration in months, mean (SD)	124.0 (42.9)	124.2 (42.0)	123.6 (45.0)
Diabetes regimen, %			
Insulin pump	3.4	3.6	2.9
Insulin long-acting 3+ rapid acting injections	17.2	14.7	22.5
Any other combo of insulin injections	32.8	34.8	28.4
Oral hypoglycemic medication	19.6	19.2	20.6
No treatment	27.0	27.7	25.5
Continuous glucose monitoring use, %	18.4	17.0	21.6
Household Income, %[b]			
<$25,000	50.6	46.4	58.7
$25,000–49,999	32.5	29.6	38.0
$50,000–74,999	7.8	10.6	2.2
$75,000+	9.2	13.4	1.1
Body Mass Index, mean (SD)	36.5 (9.2)	36.3 (8.8)	36.8 (10.2)
HbA1c, mean (SD)	9.4 (2.9)	9.5 (3.0)	9.2 (2.8)
Glycemic control, %			
Optimal	26.7	25.5	29.4
Suboptimal	18.1	19.6	14.7
Poor	55.2	54.9	55.9

(Continues)

TABLE 1 (Continued)

Characteristic	Total	Food secure ($n = 224$)	Food insecure ($n = 102$)
Diabetic ketoacidosis, %[c]	8.2	5.5	14.4
Severe hypoglycemia, %[d]	4.1	3.8	4.7

[a]Other race includes Native American, Asian-Pacific Islander, and other races.
[b]*n* of household income = 271.
[c]*n* of diabetic ketoacidosis only = 340 (86.1%).
[d]*n* of severe hypoglycemia only = 345 (87.3%).

TABLE 2 Association between household food insecurity and HbA1c and glycemic control in SEARCH youth and young adults with youth-onset type 2 diabetes ($n = 326$)

	Model 1[a]			Model 2[b]			Model 3[c]		
	Estimate (SE)		*p*-Value	Estimate (SE)		*p*-Value	Estimate (SE)		*p*-Value
Outcome: HbA1c (%)									
HFI (dichotomous)	−0.27 (0.35)		0.44	−0.23 (0.36)		0.52	−0.33 (0.34)		0.33
HFI (continuous)	−0.01 (0.08)		0.92	0.02 (0.08)		0.82	−0.02 (0.08)		0.75
	Odds ratio	CI	*p*-Value	Odds ratio	CI	*p*-Value	Odds ratio	CI	*p*-Value
Outcome: glycemic control[d]									
HFI (dichotomous)	0.90	0.57–1.41	0.63	1.14	0.71–1.84	0.60	1.02	0.61–1.69	0.94
HFI (continuous)	0.97	0.87–1.07	0.50	1.05	0.94–1.17	0.38	1.02	0.91–1.14	0.78

Abbreviations: CI, confidence interval; HFI, household food insecurity; SE, standard error.
[a]Model 1 Unadjusted model.
[b]Model 2 adjusted for: age, sex, race and ethnicity, parent education, insurance level, clinic.
[c]Model 3 adjusted for: age, sex, race and ethnicity, parent education, insurance level, clinic, diabetes duration, continuous glucose monitoring use, medication regimen.
[d]Glycemic control categories: optimal (reference), suboptimal, poor.

association between HFI and DKA yielded 340 participants, and the analysis for the association between HFI and severe hypoglycemia yielded 345 participants.

2.6 | Statistical analysis

All analyses were performed in SAS 9.4. The relationship between HFI and HbA_{1c} was assessed with linear regression. To evaluate the association between HFI and glycemic control, multinomial logistic regression via a proportional-odds cumulative logit model was used. Finally, logistic regression was used to assess the association between HFI and experiencing DKA, or severe hypoglycemia. All models were adjusted for the participant's age, diabetes duration, sex, race and ethnicity, SEARCH clinic site, parent education, insurance type, medication regimen, and continuous glucose monitoring use.

3 | RESULTS

Descriptive characteristics of the sample of YYA with type 2 diabetes can be found in Table 1. Most were young adults (mean age: 24.7, SD: 4.3, range 11.0–35.6; 95% ≥ 18 years) female (67.5%), Hispanic, non-Hispanic Black, or Other (80.7%), and class II obese (body mass index: 36.5, SD: 9.2). Almost 54% reported the highest parent education to be greater than a high school graduate, 43.6% had private insurance, and 27% reported not taking medication to manage diabetes. Half of the sample reported a household income less than $25,000 per year.

The mean HbA_{1c} for YYA in this study was 9.4% (SD: 2.9); with 55.2% ($n = 180$) of the sample in the poor glycemic control category. In the pasts 12 months, 8.2% ($n = 28$) reported experiencing DKA, and 4.1% ($n = 14$) reported severe hypoglycemia.

Table 2 includes results of the regression analyses between HFI, HbA_{1c} and glycemic control. For assessments where HFI was a binary indicator, HbA_{1c} levels were not significantly different in either unadjusted (Estimate: −0.27; *p*-value: 0.44) or adjusted models (Estimate: −0.33; *p*-value: 0.33). No statistically significant associations were observed between HFI and HbA_{1c} when HFI was characterized using the continuous score (Estimate: −0.02; *p*-value: 0.75). Likewise, there was no indication of an association between HFI and poor glycemic control in unadjusted nor in adjusted models.

The results of the analysis of the association between HFI and DKA and severe hypoglycemia are presented in Table 3. For YYA that had HFI, the odds of experiencing DKA was 3.08 (CI: 1.18–8.06; *p*-value: 0.02) times the odds of experiencing DKA for those without HFI after adjusting for all covariates (data not shown). This relationship was also present when using the continuous HFI score in the model (adjusted OR: 1.25; CI: 1.02–1.53; *p*-value: 0.03). The observed association was driven by those who used any regimen of insulin (insulin pump, insulin long-acting 3+ rapid acting injections, any other combo of insulin injections), as only 3 of the 28 participants reporting

TABLE 3 Association between household food insecurity and diabetic ketoacidosis ($n = 340$) and severe hypoglycemia ($n = 345$) in SEARCH youth and young adults with youth-onset type 2 diabetes

	Model 1[a]			Model 2[b]			Model 3[c]		
	Odds ratio	Confidence interval	*p*-Value	Odds ratio	Confidence interval	*p*-Value	Odds ratio	Confidence interval	*p*-Value
Outcome: DKA ($n = 340$)									
HFI (dichotomous)	2.89	1.32–6.32	0.01	2.83	1.21–6.57	0.02	3.08	1.18–8.60	0.02
HFI (continuous)	1.25	1.07–1.47	0.01	1.25	1.04–1.50	0.01	1.25	1.02–1.53	0.03
Outcome: Hypoglycemia ($n = 345$)									
HFI (dichotomous)	1.25	0.41–3.82	0.70	1.03	0.32–3.34	0.95	1.17	0.33–4.16	0.81
HFI (continuous)	1.09	0.87–1.38	0.45	1.06	0.82–1.37	0.66	1.09	0.83–1.43	0.55

Abbreviations: DKA, diabetic ketoacidosis; HFI, household food insecurity.

[a]Model 1 Unadjusted model.

[b]Model 2 adjusted for: age, sex, race and ethnicity, parent education, insurance level, clinic.

[c]Model 3 adjusted for: age, sex, race and ethnicity, parent education, insurance level, clinic, diabetes duration, continuous glucose monitoring use, medication regimen.

DKA did not use insulin. Restricting to those who utilized insulin to help manage their diabetes, the odds of experiencing DKA was 4.02 for those with vs. without HFI (CI: 1.41–11.46; *p*-value: 0.01).

The association between HFI and severe hypoglycemia was small in magnitude and not statistically significant (OR: 1.17; CI: 0.33–4.16, *p*-value: 0.81). There were no interaction effects by sex or race and ethnicity in any analysis.

4 | CONCLUSIONS

This is the first study to assess the association between HFI and glycemic control and acute complications of diabetes, including severe hypoglycemia or DKA in YYA with youth-onset type 2 diabetes. The demographics characteristics of YYA with type 2 diabetes were reflective of other studies.[6,7] More than three-fourths identified as Hispanic, Black, or Other, half had a household income less than $25,000 per year, and only 16% had a parent with an education level of bachelor's degree or higher. These characteristics have previously been reported to be associated with higher frequencies of DKA and severe hypoglycemia in YYA with type 1 diabetes.[32] The prevalence of HFI in this cohort was triple the national average in 2019 (31% vs. 10.5%),[25] which is consistent with previous studies that have also reported higher HFI among people with type 2 diabetes.[3,11]

Although studies have shown an association between HFI and glycemic control in older adults with type 2 diabetes[8–13] and in YYA with type 1 diabetes,[17,33] we did not observe a statistical association between HFI and glycemic control in YYA with type 2 diabetes. One possible explanation is that variability of HbA_{1c} was extremely constrained at very high levels among those with HFI (mean 9.5%, SD 3.0) and those without HFI (mean 9.2%, SD 2.8) in this sample. More than half (55%) of the sample had poor glycemic control and 17.8% had suboptimal glycemic control, in line with previous research.[18,34] The lack of an association between HFI and HbA_{1c} is consistent with a study by Ippolito et al, which found that older adults with type 2 diabetes utilizing food pantries had a high mean HbA_{1c} of 8.1% and that HbA_{1c} did not differ by food security status.[35]

Our hypothesis regarding HFI and DKA was supported by our data in that YYA with type 2 diabetes and HFI were more likely to experience DKA. Although DKA is uncommon in people with type 2 diabetes, when it does occur, it is likely sparked by being newly diagnosed with diabetes, not adhering to medication regimens, an acute illness, or a significant infection.[36–38] It is quite possible that illnesses and infections act as a mediator between HFI and DKA. Research supports an association between HFI and illnesses and infections. In HIV patients, HFI has been found to act as a mediator between HIV-related stigma and opportunistic infections and infections of the skin.[39] A Canadian population-based cohort study recently concluded that HFI was associated with higher mortality, and the association was especially pronounced for infectious-parasitic diseases.[40] Finally, among adults, HFI has been found to be associated with poorer self-reported physical health.[41] Future research should establish a relationship between HFI and infections in YYA with type

2 diabetes and explore infections as a mediator between HFI and DKA. Because this relationship was driven by those who use insulin to help manage their diabetes, further diabetes education programs for YYA with type 2 diabetes and HFI may decease episodes of DKA by focusing those who use insulin on self-management of diabetes during illness or infections.

Because DKA was self-reported, it is possible that DKA was mistaken for hyperglycemic hyperosmolar state (HHS), a more common acute complication of type 2 diabetes than DKA that has overlapping symptoms with DKA.[37] If DKA was mistaken for HHS by the participant, it does not change that, in our study, an acute complication of diabetes was more likely to occur in YYA with type 2 diabetes that had HFI than in those who were food secure.

Although in this study the association between HFI and severe hypoglycemia was not statistically significant, this result should be interpreted with caution because the prevalence of hypoglycemia in our sample was less than 5% ($n = 14$). Previous work assessing this research question among adults produced contrasting results.[14,16,35] For example, Ippolito et al found that very-low-food-secure participants had a higher prevalence of severe hypoglycemic episodes than food-secure participants.[35] There are several theories as to why HFI may in actuality be associated with severe hypoglycemia in YYA. Seligman et al. suggests that people with HFI cycle through food adequacy and food scarcity within a given year.[11,14,16,42] During times of scarcity, the risk of hypoglycemia is increased if medication is taken alone rather than with food or, in the presence of continued medication adherence, meals are skipped and caloric intake is reduced.[16] In a qualitative study, Liese et al[43] found that many adults with type 2 diabetes and HFI feared hypoglycemia which may have driven them to over-compensate by drinking sugary beverages and foods in excess.[43] Finally, many young adults experience a transition period of living at home to a more independent phase of life that affects diabetes self-management.[44] Future studies should replicate our analyses to confirm that a relationship between HFI and severe hypoglycemia does not exist. If future studies are able to confirm this association, education and training in managing diabetes in a food insecure household, screening for HFI, and medication modifications may help reduce the likelihood of a hypoglycemic episode among YYA with type 2 diabetes who have HFI.[15,45] Additionally, relaxing the eligibility criteria of social interventions aiming to reduce food insecurity for households of people with diabetes may help reduce the likelihood of a hypoglycemic episode.

This study is not without limitations. The measurement of HbA_{1c}, which assesses glycemic control in the last 3 months, could have been completed during a time when food was adequate, and may not be concurrent with HFI experienced during a 12-month period. Given the 12-month time-frame of the Household Food Security Survey Module, this can also lead to misclassification of self-reports. Taken together, both issues could have contributed to a type II error that incorrectly concludes there is no association between HFI and HbA_{1c} in YYA with type 2 diabetes. Both HFI and experiencing severe hypoglycemia or DKA were reflective of an entire year, making these variables more comparable. However, because they were self-reported, it is possible they were under or over-reported. Although the Household Food Security Survey Module is a robustly developed measure, and probably the most commonly used food security measure,[28] its limitations include that it does not capture specific sub-constructs of the food security construct. Specifically, none of the 18 Household Food Security Survey Module items directly assess the safety of foods and whether food is procured in socially acceptable ways. The sub-construct of the nutritional adequacy of foods is addressed through only the items on balanced meals and reliance on few, low-cost foods in the child section. The psychologic sub-constructs related to compromised choices are not addressed. Instead, the Household Food Security Survey Module focuses on uncertainty, the limited food availability and its potential consequences, and the behaviors to mitigate the impact of food shortages. Nonetheless, the Household Food Security Survey Module has been the US reference measure used for assessing and monitoring the prevalence of food insecurity in the United States since 1995. Furthermore, the evidence for the validity of the Household Food Security Survey Module and its offspring variants for assessing populations of households and differentiating households is strong. This evidence has recently been summarized by Frongillo.[46] The cross-sectional study design makes it difficult to ascertain the temporal order of exposure and outcome, which may have consequences for causal inference. We cannot truly know whether HFI or acute diabetes complications occurred first. Future research among YYA with type 2 diabetes should consider longitudinal studies to establish if alleviating HFI reduces frequency of DKA. Finally, income was ultimately removed from the model. Through conducting a sensitivity analysis, we observed that the overall results of the analyses did not differ.

There are also several strengths of our study. This is the largest study to date to assess HFI among YYA with type 2 diabetes and the first to examine a relationship between HFI and acute diabetes complications in this group. Additionally, we were able to adjust for a number of confounders that previous studies have not included, such as diabetes duration and medication regimen.

In conclusion, DKA was three times more likely to occur among those with HFI than those without, which is all the more important as the prevalence of food insecurity in this sample is much higher than in the general population[3]; however, there were no observed differences in glycemic control or experiencing severe hypoglycemia by food insecurity status. This study supports the American Diabetes Association recommendation to universally screen for and address food insecurity as tailored treatment to help people manage diabetes.[20] Universal screening of food insecurity status may improve clinical care of people with diabetes and increase awareness of providers who can help guide those with HFI to better manage their diabetes and to food assistance resources.[20]

AUTHOR CONTRIBUTIONS

Lauren A. Reid conducted the literature review, completed the analysis, and wrote the manuscript. Marco Geraci and Beth A. Reboussin provided guidance for the analysis, reviewed and edited the manuscript and contributed to discussion. Anwar T. Merchant, Faisal S. Malik, Alice M. Ellyson, Dana Dabelea, Lina Merjaneh, Santica

M. Marcovina, Eva Lustigova, and Jean M. Lawrence reviewed and edited the manuscript and contributed to discussion and final approval of the manuscript. Angela D. Liese and Jason A. Mendoza conceptualized the objective, guided the analysis, reviewed and edited the manuscript, and contributed to discussion and final approval of the manuscript. Angela D. Liese is the guarantor of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Faisal S. Malik https://orcid.org/0000-0002-2543-4214
Alice M. Ellyson https://orcid.org/0000-0001-8648-3442
Lina Merjaneh https://orcid.org/0000-0002-4769-5626
Jean M. Lawrence https://orcid.org/0000-0002-2480-8480

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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