Food insecurity and obesity among US young adults: the moderating role of biological sex and the mediating role of diet healthfulness

Yufei Li[1],* and Samantha R Rosenthal[1,2]
[1]Department of Epidemiology, Brown School of Public Health, 121 South Main Street, Providence, RI 02903, USA:
[2]Department of Health Science, College of Health & Wellness, Johnson & Wales University, Providence, RI, USA

Abstract

Objective: To examine the association between food insecurity (FI) and obesity, measured by BMI and waist circumference (WC), among young adults and test the moderating role of biological sex and the mediating role of diet healthfulness (DH).
Design: Cross-sectional.
Setting: National Health and Nutrition Examination Survey 2011–2016.
Participants: The sample included 4667 young adults aged 18–35 years.
Results: Given the interaction terms between sex and FI, biological sex was a moderator between both FI and WC ($P = 0.031$) and FI and BMI ($P = 0.007$) among young adults. FI was associated with a $1.16 \, \text{kg/m}^2$ higher BMI (95 % CI 0.27, 2.05) and a 2.09 cm larger WC (95 % CI 0.05, 4.14) among young female adults, while FI was associated with a $0.26 \, \text{kg/m}^2$ higher BMI (95 % CI −0.65, 1.16) and a 0.78 cm larger WC (95 % CI −1.13, 2.89) among young male adults. DH mediated the relationships between both FI and BMI (indirect effect $\beta = 0.14$; 95 % CI 0.05, 0.23) and FI and WC (indirect effect $\beta = 0.31$; 95 % CI 0.10, 0.51) among females. Females with FI had poorer DH and thus had higher BMI and larger WC.
Conclusions: Young female adults with FI were more likely to experience overall and abdominal obesity compared with their male counterparts. Results also suggest that females with FI had poorer DH and thus had increased risk of both abdominal and overall obesity.

Food insecurity (FI) is defined as limited access to adequate healthy food because of insufficient household money or other resources[1]. According to a survey in 2018, about 11·1 % of US households were food insecure at some point in the year[2]. FI is a major public health concern with a variety of adverse medical outcomes such as depression, diabetes and CVD[3–5]. Research has shown an association between elevated FI and obesity among women[6–9]. Other studies in men were limited and the results were inconsistent[6,9–11]. Few studies have focused on young adulthood, a critical time period for the transition to self-sufficiency and the development of obesity[12]. Research has shown that young adults (18–35 years of age) are more vulnerable to weight gain than all other age groups[13,14]. In addition, the increasing risk of metabolic syndrome and CVD among young adults worsens through the life course[15]. Thus, weight

gain prevention among young adults would have significant implications for long-term health benefits.

Although there has been much evidence indicating the link between FI and obesity[6–11], the mechanism through which this occurs remains unclear[16,17]. Several studies indicated that individuals experiencing FI tend to alternate between hunger and consumption of energy-dense unhealthy foods[18,19] to avoid the higher cost of healthy foods such as lean meat, fruits and vegetables[20]. This compensatory dietary pattern could lead to cyclical weight gain[21,22], while other studies found that the availability of unhealthy foods was associated with obesity but did not play a mediating role[23]. Therefore, the potential mediating role of diet healthfulness (DH) between FI and obesity is worth further investigation.

BMI has been the most commonly used tool to determine obesity[6–12,24]. However, this method fails to distinguish

Corresponding author: Email yufei_li1@brown.edu

between fat and fat-free mass[25]. In fact, research has found that waist circumference (WC), a way to assess abdominal obesity, is a more accurate method to measure body composition and predict obesity-related health risk[25,26]. Thus, both BMI and WC were used to measure overall obesity and abdominal obesity, respectively, in the current study.

The objective of the current study was to clarify the relationship between FI and WC, FI and BMI among young adults aged 18–35 years using data from The National Health and Nutrition Examination Survey, 2011–2016. In addition, the study examined whether biological sex modified the main effects, and whether DH played a mediating role in the relationship.

Methods

Study sample
The National Health and Nutrition Examination Survey is a cross-sectional representative survey conducted by the National Center for Health Statistics and the Centers for Disease Control and Prevention[27] that uses a complex, multistage probability design to sample the civilian, non-institutionalised population in the USA. Our study combined data from the 2011–2012, 2013–2014 and 2015–2016 National Health and Nutrition Examination Survey cycles, the most recent survey years for FI data. During these cycles, Hispanics, non-Hispanic Asians, non-Hispanic Blacks, older adults and low-income Whites/others were oversampled by the design. Full details of the study design, recruitment and procedures are available at the Department of Health and Human Services[27]. Out of the total sample (*n* 29 902), 5640 participants were aged 18–35 years; 17·25 % of them (*n* 973) were excluded due to missing values of FI, BMI, WC, DH or general health, resulting in 4667 participants in the final sample.

Measures

Food insecurity
The 10-item US Food Security Survey Module was used to assess adult FI status[28]. It asked about the size of meals, skipping meals and not eating for a whole day. Similar to previous studies, an affirmative answer on at least one of these ten items was defined as 'food insecurity'[29,30].

Body mass index
BMI (kg/m^2) was calculated as weight in kilograms divided by height in meters squared and then rounded to one decimal place.

Waist circumference
WC (cm) was taken to the nearest 1 mm, measured at the level of iliac crest in the Mobile Examination Center[27]. For males, WC larger than 102 cm was defined as abdominal obesity, and for females, WC larger than 88 cm was defined as abdominal obesity[31].

Diet healthfulness
The potential mediating variable was the self-appraised healthfulness level of one's own diet. Participants were asked 'In general, how healthy was your overall diet over the past 12 months?' The ratings were made on a five-point scale from excellent to poor (1: excellent, 2: very good, 3: good, 4: fair, 5: poor).

Biological sex
Biological sex was self-reported by participants as male or female.

Covariates
Other variables including age, race (Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, non-Hispanic Asian, other), country of birth (US *v.* other countries), self-reported general health (1: excellent, 2: very good, 3: good, 4: fair, 5: poor) and family poverty-to-income ratio (<=1·3 *v.* >1·3) were included in the analyses as potential confounders. The cutoff of 1·30 for family poverty-to-income ratio was chosen because it is the eligible cutoff for federal nutrition support programmes such as the Supplemental Nutrition Assistance Program and the National School Lunch Program[32].

Statistical analysis
Univariate analyses were performed to describe every variable of interest for the entire sample and for each biological sex. Continuous variables, including age, BMI and WC, were described with weighted means and SD. Categorical variables, including race, country of birth, FI, DH, general health and income-to-poverty ratio, were described with unweighted frequencies and weighted percentages.

Bivariate analyses of the covariates with FI, BMI and WC were done separately. Chi-square tests were conducted to test the relationships between FI and categorical covariates (i.e., race, biological sex, country of birth, general health and income-to-poverty ratio). Simple linear regression tests were conducted to test the relationships between BMI and all the covariates, and also WC and all the covariates. The association between FI and age, BMI and WC was examined by simple linear regression tests as well.

Two multiple linear regression models controlling for potential confounders were used to assess the association between FI and BMI, and also FI and WC in the overall sample. Diagnostic tests were conducted for the normality assumption, outlier detection and multicollinearity. Interaction terms of biological sex and FI were then created and added to the models to test if biological sex was an effect modifier. Stratified analyses within each biological sex were also conducted.

We further adjusted for education and marital status to assess the main effects of FI on BMI and WC for the entire sample and for each biological sex as sensitivity analyses. We also examined the dose–response relationships between FI and BMI, and FI and WC using tests for trend depending
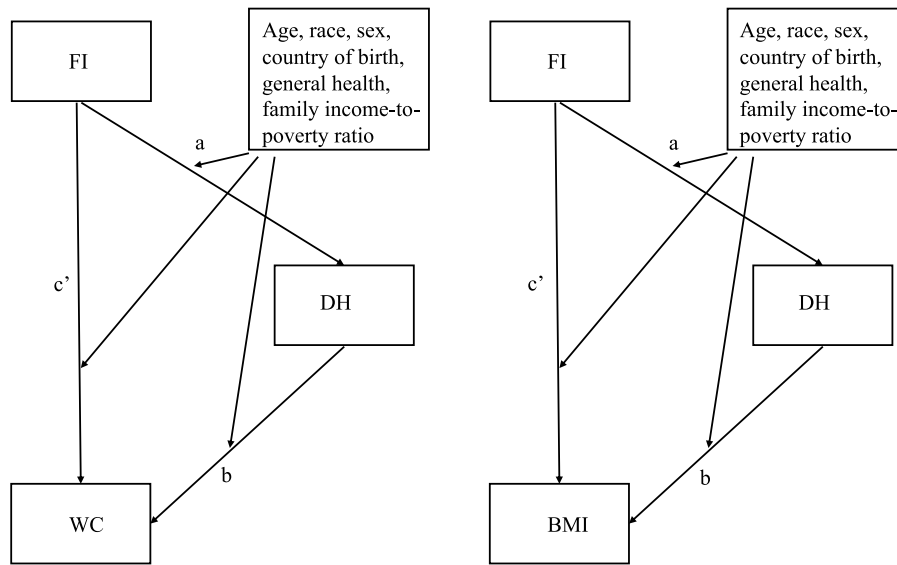
Fig. 1 Mediation effects of DH between FI and BMI, and FI and WC. DH, diet healthfulness; FI, food insecurity; WC, waist circumference

on the number of affirmative answers in the Food Security Survey Module (full security: 0, marginal food security: 1–2, low food security: 3–5, very low food security: 6–10) for males and females. Tests for trend were conducted using simple linear regression models stratified by biological sex.

Structural equation modelling was used to explore if the effects of FI on BMI and FI on WC were mediated by DH. Structural equation modelling is an approach to examine both the direct (c') and indirect effects (a * b) of FI on BMI and FI on WC. Figure 1 provided the basic theoretical forms of the structural equation models tested. All of the models were adjusted for age, race, country of birth, general health and family income-to-poverty ratio. For all analyses, survey sampling weights were applied to take into account the complex sampling strategy of the National Health and Nutrition Examination Survey and increase the representativeness of the sample. We used a P value < 0.05 to assess significance. All analyses were performed using SAS 9.4 (SAS Institute).

Results

The weighted average age of the entire sample (n 4667) was 26·33 years (sd = 0·14 years). Females comprised 48 % of the sample and males 52 %. The descriptive statistics for the entire sample and for each biological sex are listed in Table 1. The WC of females was lower than that of males ($P < 0.001$), while the BMI was higher ($P = 0.049$). The prevalence of abdominal obesity among females was much higher than that among males ($P < 0.001$). Males had higher income-to-poverty ratio than females ($P = 0.002$). Females reported better DH than males ($P = 0.044$). The descriptive statistics for people who were food secure and food insecure are listed in Table 2. People who were

food secure comprised 66 % of the sample and food insecure 34 %. We further compared our variables of interest between eligible participants (i.e., participants aged 18–35 years) who were included and those excluded (due to missing values) from the analyses. The results indicated that those who are younger, non-Hispanic White, males, born in the USA and with higher income-to-poverty ratio were more likely to be included (see online supplementary material, Supplemental Table 1).

Results of bivariate analyses between FI and covariates are as follows (Table 2): Simple linear regression tests showed that FI was associated with age ($P = 0.016$), BMI ($P < 0.001$) and WC ($P = 0.002$). Specifically, people with FI were younger, had larger WC and higher BMI. Chi-square tests showed that FI was associated with race ($P < 0.001$). Specifically, 50 % of Hispanic and 47 % of non-Hispanic Black participants were food insecure, while 26 % of non-Hispanic White and 31 % of others were food insecure. People who were born in other countries (40 %) were more likely to be food insecure compared with people who were born in the USA (33 %; $P = 0.012$). A greater percentage of people with lower income-to-poverty ratio (54 %) were food insecure compared to people with higher income-to-poverty ratio (23 %; $P < 0.001$). FI was also associated with DH ($P < 0.001$). Specifically, people who reported worse DH were also more likely to be food insecure: 22 % of excellent/very good, 32 % of good and 46 % of fair/poor DH. People who had worse general health were also more likely to be food insecure ($P < 0.001$; 25 % of excellent/very good, 38 % of good and 55 % of fair/poor general health).

Results of bivariate analyses between BMI, WC and covariates by simple linear regressions were as follows: Both BMI and WC were associated with age ($P < 0.001$), country of birth ($P < 0.001$), race ($P < 0.001$) and general

Table 1 Characteristics of participants aged 18–35 years by biological sex, NHANES, 2011–2016

	Total (n 4667)		Male (n 2385)		Female (n 2282)		
	n	%	n	%	n	%	P*
Age							0·716
Mean	26·33		26·36		26·31		
SD	0·14		0·14		0·17		
Waist circumference (cm)							<0·001
Mean	94·00		95·23		92·67		
SD	0·50		0·60		0·53		
BMI (kg/m²)							0·049
Mean	27·89		27·70		28·10		
SD	0·20		0·23		0·21		
Abdominal obesity*							<0·001
Yes	1835	40	661	29	1174	52	
No	2832	60	1724	71	1108	48	
Race*							0·164
Hispanic	1196	20	579	20	617	20	
Non-Hispanic White	1592	58	839	58	753	57	
Non-Hispanic Black	1052	13	523	12	529	14	
Others	827	10	444	10	383	10	
Country of birth*							0·114
USA	3521	83	1783	82	1738	84	
Other countries	1146	17	602	18	544	17	
Food insecurity*							0·248
0 (secure)	2787	66	1436	67	1351	65	
1 (insecure)	1880	34	949	33	931	35	
Food insecurity*							0·516
Full security	2787	66	1436	67	1351	65	
Marginal security	705	13	349	12	356	14	
Low security	659	12	331	11	328	12	
Very low security	516	9	269	9	247	9	
Diet healthfulness*							0·044
Excellent/very good	1071	24	580	24	491	24	
Good	1988	44	983	42	1005	46	
Fair/poor	1608	32	822	34	786	30	
General health*							0·129
Excellent/very good	2020	47	1097	48	923	46	
Good	1941	41	980	41	961	41	
Fair/poor	706	13	308	12	398	14	
Income-to-poverty ratio†							0·002
<1·3	2059	35	1015	33	1044	37	
≥1·3	2608	65	1370	67	1238	63	

NHANES, National Health and Nutrition Examination Survey.
*P values were generated using chi-square tests or t-tests.
†The weighted % uses the analytic weights to generate population-based estimates of prevalence for the included sample. Numbers may not sum to 100 % due to rounding.

health ($P < 0.001$), but not with family income-to-poverty ratio (WC: $P = 0.710$; BMI: $P = 0.551$).

The multiple linear regression models between FI and BMI, and FI and WC controlled for age, race, biological sex, country of birth, general health and family income-to-poverty ratio. No outliers were excluded in the analysis, and there was no multicollinearity detected in the model (min (Tolerance) = 0·89, max (VIF) = 1·12). Among the total sample, the data were relatively consistent with an association between FI and BMI ($P = 0.052$), and FI and WC ($P = 0.088$) (Table 3). Also, when the interaction terms of FI and biological sex were added into the models, we found interaction effects of FI and sex for both BMI ($P = 0.007$) and WC ($P = 0.031$). Specifically, FI was associated with both BMI ($P = 0.012$) and WC ($P = 0.045$) among females (Table 3). Females who were food insecure had BMI 1·16 (95 % CI 0·27, 2·05) kg/m² higher on average than those who were food secure and had WC 2·09 (95 % CI

0·05, 4·14) cm larger. However, the data did not support similar relationships among males, neither the association between FI and BMI ($P = 0.568$) nor WC ($P = 0.462$). Additional adjustments for education and marital status did not change the results (see online supplementary material, Supplemental Table 2), but since the values were largely missing for these two variables, we did not include them in the main results. The results of the dose–response relationships between FI and BMI, and FI and WC for each biologicals sex were shown in Table 4. The effect estimates indicated trend effects between FI and BMI, and FI and WC among females, but not among males.

Given the associations between FI and BMI, and FI and WC among females, we further conducted mediation analyses of FI and BMI, and FI and WC among females with two structural equation models. The results (Table 5) indicated that DH was a mediator between FI and BMI ($P = 0.003$). The total effect of FI on BMI ($c = 0.93$,

Table 2 Characteristics of participants aged 18–35 years by food insecurity, NHANES, 2011–2016

	Food secure (n 2787)		Food insecure (n 1880)		P*
	n	%	n	%	
Age					0·016
Mean	26·53		25·95		
SD	0·14		0·23		
Waist circumference (cm)					0·002
Mean	93·05		95·85		
SD	0·57		0·74		
BMI (kg/m^2)					<0·001
Mean	27·39		28·87		
SD	0·23		0·29		
Race†					<0·001
Hispanic	573	50	623	50	
Non-Hispanic White	1073	74	519	26	
Non-Hispanic Black	548	53	504	47	
Others	593	69	234	31	
Country of birth†					0·012
USA	2103	67	1418	33	
Other countries	684	60	462	40	
Biological sex†					0·248
Male	1436	67	949	33	
Female	1351	65	931	35	
Diet healthfulness†					<0·001
Excellent/very good	748	78	323	22	
Good	1242	68	746	32	
Fair/poor	797	54	811	46	
General health†					<0·001
Excellent/very good	1377	76	643	25	
Good	1105	62	836	38	
Fair/poor	305	45	401	55	
Income-to-poverty ratio†					<0·001
<1·3	903	46	1156	54	
≥1·3	1884	77	724	23	

NHANES, National Health and Nutrition Examination Survey.
*P values were generated using chi-square tests or t-tests.
†The weighted % uses the analytic weights to generate population-based estimates of prevalence for the included sample. Numbers may not sum to 100 % due to rounding.

Table 3 Weighted multiple linear regression analysis stratified by sex predicting the association between food insecurity and BMI, and food insecurity and waist circumference*

	Total (n 4667)		Male (n 2385)		Female (n 2282)	
	β	95 % CI	β	95 % CI	β	95 % CI
BMI	0·71	−0·01, 1·42	0·26	−0·65, 1·16	1·16	0·27, 2·05
WC	1·42	−0·22, 3·06	0·78	−1·33, 2·89	2·09	0·05, 4·14

WC, waist circumference.
*All the regression models were adjusted for controlling confounders (age, race, country of birth, general health and income-to-poverty ratio). Biological sex was additionally adjusted for the total model.

Table 4 Dose–response relationship between FI and BMI, and FI and WC for males and females

	BMI				WC			
	Female		Male		Female		Male	
FI	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Full security	26·56	0·17	27·48	0·25	91·11	0·61	94·80	0·69
Marginal security	28·81	0·49	28·24	0·60	93·86	1·33	96·30	1·50
Low security	29·93	0·46	28·13	0·72	96·51	1·10	95·57	1·68
Very low security	30·29	0·63	28·09	0·52	96·92	1·48	96·50	1·44
P$_{for trend}$*	<0·001		0·19		<0·001		0·28	

FI, food insecurity; WC, waist circumference.
*Simple linear regression was used to calculate P$_{for trend}$.

Public Health Nutrition

Table 5 Total, direct and mediation effects for BMI and WC among females*

Outcome	Total effect		Indirect effect		Direct effect		Percentage mediated	
	c	95 % CI	a * b	95 % CI	c'	95 % CI	%	95 % CI
BMI	0·93	0·30, 1·56	0·14	0·05, 0·23	0·80	0·17, 1·42	14·64	1·57, 27·70
WC	1·54	0·09, 2·99	0·31	0·10, 0·51	1·23	−2·11, 2·67	20·01	−1·89, 41·91

WC, waist circumference.
*All the structural equation models were adjusted for controlling confounders (age, race, country of birth, general health and income-to-poverty ratio).

95 % CI 0·30, 1·56) could be decomposed into a direct effect of FI on BMI conditioning on DH (c' = 0·80, 95 % CI 0·17, 1·42) and an indirect effect through DH (a * b = 0·14, 95 % CI 0·05, 0·23); 14·64 % (95 % CI 1·57 %, 27·70 %) of the total effect between FI and BMI could be explained by DH. DH was also a mediator between FI and WC (P = 0·003). The total effect of FI on WC (c = 1·54, 95 % CI 0·09, 2·99) could be decomposed into the direct effect of FI on WC conditioning on DH (c' = 1·23, 95 % CI −2·11, 2·67) and the indirect effect through DH (a * b = 0·31, 95 % CI 0·10, 0·51); 20·01 % (95 % CI −1·89 %, 41·91 %) of the total effect between FI and WC could be explained by DH. Females who were food insecure had poorer DH on average and thus had higher BMI and larger WC. Confounding covariates, including age, race, country of birth, general health and family income-to-poverty ratio, were adjusted in the model.

Discussion

The current study used BMI and WC as measurements of overall obesity and abdominal obesity, respectively, to characterise the relationship between FI and obesity of young adults aged 18–35 years in a large, nationally representative sample. Specifically, we examined whether biological sex moderated the relationship and whether DH mediated the relationship.

Our study found positive relationships between FI and BMI, and FI and WC among young adults when controlling for age, race, country of birth, general health and family income-to-poverty ratio. The results are comparable to previous studies[33,34], but the P-values are not particularly low. This is likely due to limited power and differences in study age group, sample size, study design, FI measurement or selection of potentially confounding variables. In addition, our findings indicated that biological sex played a moderating role between FI and BMI, and FI and WC among this population. Specifically, there was a positive association between FI and both BMI and WC among females, which was consistent with previous research[6–9,35]. There was no association of such among males. We also found positive dose–response relationships between FI and BMI, and FI and WC among females. In other words, for females, the greater the severity of FI, the higher their BMI and the larger their WC on average. These dose–response relationships were not detected among males.

These results suggest that young male and female adults act differently in the face of FI[10]. Females were more likely to feed themselves unhealthy food in response to FI. Yet males were less likely to do so. It also suggests that alleviating the severity of FI for females, even if not being able to fully eliminate FI, could provide benefits for maintaining healthy weight. The sex difference regarding FI and obesity could be caused by the fact that females were in general more responsible for food selection and preparation for the family[36], and they are thus more aware of food scarcity in the household and react accordingly. It could also be caused by the stress induced by FI[37], and females are more likely to increase food intake when under stress compared with males[38,39], especially high fat and sweet foods[40]. Yet it is noteworthy that the vast majority (71 %) of young male adults in this population were below the cutoff of WC recommended by American Heart Association for elevated cardiometabolic risk[31]. On the other hand, a majority (52 %) of females in this population had met the cutoff and were at high risk of obesity-related health conditions[26,41]. The average BMI among females (28·10 kg/m²) was also higher than that of males (27·70 kg/m²) in this population.

In the current study, DH was a mediator between FI and WC among females. In other words, the effects of FI on BMI, and FI on WC among females were mediated by DH. Specifically, females with FI had poorer self-reported DH, and females with poorer self-reported DH had higher levels of BMI and WC. This finding was in line with previous studies testing the mediating role of dietary behaviour between FI and obesity among youth[33,42]. This suggests that improving diets would be beneficial for people with FI to maintain healthy weight.

The implications of these findings are twofold. First, community-based DH education should be implemented to promote self-awareness of adopting healthy eating habits such as eating breakfast regularly, avoiding snack consumption and sugary drinks among people with FI, especially females. Second, healthcare providers should try to identify people who are at risk or are currently experiencing FI and provide them with appropriate social services resources such as applying for federal nutrition assistance programmes to get nutritious and sufficient food and thus maintain healthy weight.

There were several limitations in the current study. The current study was cross-sectional study, and therefore causal relationships between FI and BMI, and FI and WC

could not be demonstrated. The cross-sectional study did not account for the duration of FI, which is also important for the development of obesity[43]. In addition, the cross-sectional approach could result in substantial bias in the mediation analysis[44]. The mediator identified in the current study may not be a mediator in longitudinal studies[44]. Thus, longitudinal studies examining the long-term effect of FI on BMI and WC and the potential mediating effect of DH are needed in the future. Additionally, some potential confounders, such as education status, marital status and number of children, were largely missing in the dataset and, thus, were not controlled for in the analyses – yet, sensitivity analyses controlling for education and marital status showed the same results. Behavioural variables regarding participants' physical activities and smoking and drinking behaviours were not controlled for in our analyses and should be included in future studies as well. Furthermore, since young adults with missing values for variables of interest were excluded from the analysis, participants included and excluded from the analyses had different socio-demographic characteristics. The selection effect made our results more applicable for people who were younger, White, born in the USA and had higher income. Finally, we used self-reported measures of FI, and participants were asked to recall their food situation for the previous 12 months. One potential problem could be inaccurate recollection, which may lead to misclassification of FI[45]. In addition, DH was measured by a self-reported single question. It was more of a proxy measure and did not fully capture eating behaviours or actual energy intake. More objective measures should be applied in future studies.

Conclusion

In conclusion, the current study showed the moderating role of biological sex between FI and BMI, and FI and WC among US young adults. Females with FI were more likely to have higher BMI and larger WC compared with those without FI, while these same relationships were absent for males. The current study also showed that DH was a mediator between FI and BMI, and FI and WC among females. Females with FI had poorer DH and thus had higher BMI and larger WC. These findings should inform more accessible diet health education programmes and nutrition assistance programmes for vulnerable populations.

Acknowledgements

Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980020004577

References

1. Coleman-Jensen A, Gregory C & Singh A (2014) *Household Food Security in the United States in 2013,* ERR-173, U.S. Department of Agriculture, Economic Research Service.
2. Coleman-Jensen A, Rabbit MP, Gregory CA *et al.* (2019) *Statistical Supplement to Household Food Security in the United States in 2018. USDA-ERS Economic Research Report* no 270. USDA, ERS.
3. Leung CW, Epel ES, Willett WC *et al.* (2015) Household food insecurity is positively associated with depression among low-income supplemental nutrition assistance program participants and income-eligible nonparticipants. *J Nutr* **145**, 622–627.
4. Seligman HK, Bindman AB, Vittinghoff E *et al.* (2007) Food insecurity is associated with diabetes mellitus: results from the National Health Examination and Nutrition Examination Survey (NHANES) 1999–2002. *J Gen Intern Med* **22**, 1018–1023.
5. Saiz AM, Aul AM, Malecki KM *et al.* (2016) Food insecurity and cardiovascular health: findings from a statewide population health survey in Wisconsin. *Prev Med* **93**, 1–6.
6. Townsend MS, Peerson J, Love B *et al.* (2001) Food insecurity is positively related to overweight in women. *J Nutr* **131**, 1738–1745.
7. Gooding HC, Walls CE & Richmond TK (2012) Food insecurity and increased BMI in young adult women. *Obesity* **20**, 1896–1901.
8. Adams EJ, Grummer-Strawn L & Gilberto C (2003) Food insecurity is associated with increased risk of obesity in California women. *J Nutr* **133**, 1070–1074.
9. Wilde PE & Peterman JN (2006) Individual weight change is associated with household food security status. *J Nutr* **136**, 1395–1400.
10. Hernandez DC, Reesor LM & Murillo R (2017) Food insecurity and adult overweight/obesity: gender and race/ethnic disparities. *Appetite* **117**, 373–378.
11. Larson NI & Mary TS (2011) Food insecurity and weight status among US children and families: a review of the literature. *Am J Prev Med* **40**, 66–173.
12. Suchindran C, North KE, Popkin BM *et al.* (2010) Association of adolescent obesity with risk of severe obesity in adulthood. *JAMA* **304**, 2042–2047.
13. McTigue KM, Garrett JM & Popkin BM (2002) The natural history of the development of obesity in a cohort of young US adults between 1981 and 1998. *Ann Intern Med* **136**, 857–864.
14. Sheehan TJ, DuBrava S, DeChello LM *et al.* (2003) Rates of weight change for black and white Americans over a 20-year period. *Int J Obes Relat Metab Disord* **27**, 498–504.
15. Truesdale KP, Stevens J, Lewis CE *et al.* (2006) Changes in risk factors for cardiovascular disease by baseline weight status in young adults who maintain or gain weight over 15 years: the CARDIA study. *Int J Obes* **30**, 1397–1407.

16. Franklin B, Jones A, Love D et al. (2012) Exploring mediators of food insecurity and obesity: a review of recent literature. J Community Health 37, 253–264.

17. Rogers BG, Kegler MC, Berg CJ et al. (2016) Understanding the food insecurity and obesity relationship by examining potential mediators: an exploratory analysis. J Hunger Environ Nutr 11, 195–209.

18. Widome R, Neumark-Sztainer D, Hannan PJ et al. (2009) Eating when there is not enough to eat: eating behaviors and perceptions of food among food-insecure youths. Am J Public Health 99, 822–828.

19. Tester JM, Lang TC & Laraia BA (2016) Disordered eating behaviours and food insecurity: a qualitative study about children with obesity in low-income households. Obes Res Clin Pract 10, 544–552.

20. Drewnowski A (2010) The cost of US foods as related to their nutritive value. Am J Clin Nutr 92, 1181–1188.

21. Seligman HK & Schillinger D (2010) Hunger and socioeconomic disparities in chronic disease. N Engl J Med 363, 6–9.

22. Ambrosini GL (2014) Childhood dietary patterns and later obesity: a review of the evidence. Proc Nutr Soc 73, 137–146.

23. Kowaleski-Jones L, Wen M & Fan JX (2019) Unpacking the paradox: testing for mechanisms in the food insecurity and BMI association. J Hunger Environ Nutr 14, 683–697.

24. Clinical Guidelines on the Identification (1998) Evaluation, and treatment of overweight and obesity in adults—the evidence report. National Institutes of Health. Obes Res 6, Suppl. 2, S51–S209.

25. Fedewa MV, Brett SN & Michael RE (2019) Associations of body adiposity index, waist circumference, and body mass index in young adults. Clin Nutr 38, 715–720.

26. Janssen I, Peter TK & Robert R (2004) Waist circumference and not body mass index explains obesity-related health risk. Am J Clin Nutr 79, 379–384.

27. Centers for Disease Control and Prevention (2020) National Center for Health Statistics. National Health and Nutrition Examination Survey. Hyattsville, MD: Department of Health and Human Services, CDC. http://www.cdc.gov/nchs/nhanes. htm (accessed February 2020).

28. Bickel G, Nord M, Price C et al. (2000) Guide to Measuring Household Food Security. Alexandria, VA: US Department of Agriculture, Food and Nutrition Service.

29. Portela-Parra ET & Leung CW (2019) Food insecurity is associated with lower cognitive functioning in a national sample of older adults. J Nutr 149, 1812–1817.

30. Gundersen C & Ziliak JP (2015) Food insecurity and health outcomes. Health Aff (Millwood) 34, 1830–1839.

31. Klein S, Allison DB, Heymsfield SB et al. (2007) Waist circumference and cardiometabolic risk: a consensus statement from shaping America's health: association for Weight Management and Obesity Prevention; NAASO, the Obesity Society; the American Society for Nutrition; and the American Diabetes Association. Obesity 15, 1061–1067.

32. Kaur J, Lamb MM & Ogden CL (2015) The association between food insecurity and obesity in children – The National Health and Nutrition Examination Survey. J Acad Nutr Diet 115, 751–758.

33. Wu CH, Lin CY, Hsieh YP et al. (2019) Dietary behaviors mediate the association between food insecurity and obesity among socioeconomically disadvantaged youth. Appetite 132, 275–281.

34. Souza BF & Marín-León L (2013) Food insecurity among the elderly: cross-sectional study with soup kitchen users. Revista de Nutrição 26, 679–691.

35. Gooding HC, Walls CE & Richmond TK (2012) Food insecurity and increased BMI in young adult women. Obesity (Silver Spring) 20, 1896–1901.

36. McIntosh A & Zey M (1989) Women as gatekeepers of food consumption: a sociological critique. Food and Foodways 3, 317–332.

37. Martin MS, Maddocks E, Chen Y et al. (2016) Food insecurity and mental illness: disproportionate impacts in the context of perceived stress and social isolation. Public Health 132, 86–91.

38. Epel E, Lapidus R, McEwen B et al. (2001) Stress may add bite to appetite in women: a laboratory study of stress-induced cortisol and eating behavior. Psychoneuroendocrinology 26, 37–49.

39. Al-Asadi JN (2014) Perceived stress and eating habits among medical students. Int J Med Pharm Sci 4, 81–90.

40. Habhab S, Sheldon JP & Loeb RC (2009) The relationship between stress, dietary restraint, and food preferences in women. Appetite 52, 437–444.

41. Beydoun MA & Wang Y (2009) Gender-ethnic disparity in BMI and waist circumference distribution shifts in US adults. Obesity (Silver Spring) 17, 169–176.

42. Smith C & Richards R (2008) Dietary intake, overweight status, and perceptions of food insecurity among homeless Minnesotan youth. Am J Hum Biol 20, 550–563.

43. Wells NM, Evans GW, Beavis A et al. (2010) Early childhood poverty, cumulative risk exposure, and body mass index trajectories through young adulthood. Am J Public Health 100, 2507–2512.

44. Maxwell SE, Cole DA & Mitchell MA (2011) Bias in cross-sectional analyses of longitudinal mediation: partial and complete mediation under an autoregressive model. Multivariate Behav Res 46, 816–841.

45. Coughlin SS (1990) Recall bias in epidemiologic studies. J Clin Epidemiol 43, 87–91.