Neighborhood Deprivation and Change in BMI Among Adults With Type 2 Diabetes

The Diabetes Study of Northern California (DISTANCE)

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OBJECTIVE—To compare associations between neighborhood deprivation and measures of BMI change among adults with type 2 diabetes.

RESEARCH DESIGN AND METHODS—Using data from the Kaiser Permanente Diabetes Study of Northern California (DISTANCE) survey, we estimated the association between neighborhood deprivation and two measures of BMI change over 3 years: *1*) a continuous measure and 2) a categorical measure of clinically substantive BMI loss or gain (≥7% of baseline BMI) versus stable BMI. The sample included 13,609 adults.

RESULTS—On average, there was little change in BMI (−0.12, SD 3.07); 17.0 and 16.1% had clinically substantive BMI loss or gain, respectively, at follow-up. There was a positive association between neighborhood deprivation and BMI change for adults in the most versus least-deprived quartile of neighborhood deprivation (β = 0.22, *P* = 0.02) in adjusted models. In addition, relative to the least-deprived quartile (Q1), adults in more-deprived quartiles of neighborhood deprivation were more likely to experience either substantive BMI loss (Q2 relative risk ratio 1.19, 95% CI 1.00–1.41; Q3 1.20, 1.02–1.42; Q4 1.30, 1.08–1.55) or gain (Q2 1.25, 1.04–1.49; Q3 1.24, 1.04–1.49; Q4 1.45, 1.20–1.75).

CONCLUSIONS—Greater neighborhood deprivation was positively associated with BMI change among adults with diabetes as well as with clinically substantive BMI loss or gain. Findings stress the importance of allowing for simultaneous associations with both gain and loss in future longitudinal studies of neighborhood deprivation and weight change, which may be particularly true for studies of patients with diabetes for whom both weight loss and gain have health implications.

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In the search for modifiable risk factors related to unhealthy weight, a growing literature has focused on the influence of neighborhood deprivation. Neighborhood deprivation may affect weight through differential access to safe places to exercise (1) and nutritious foods (2) or through chronic environmental stressors (3,4). Cross-sectional studies have found positive associations between neighborhood deprivation and unhealthy weight (5,6). However, longitudinal studies, which provide a stronger basis for causation, have yielded mixed results, with some finding no association (6) and others finding a positive association (7,8) between neighborhood deprivation and weight change. These inconsistencies may be a result of differences in study populations, length of follow-up, or specification of neighborhood deprivation (9,10). However, they may also be the result of failure to take into account the complexity of weight change, particularly among adults with chronic conditions like diabetes. In such populations, in which most individuals are trying to lose weight, the spectrum of possible outcomes includes weight loss, gain, fluctuation (i.e., loss and regain), and stability (11). The relationship between neighborhood deprivation and weight change over time among adults is shape variant and potentially nonlinear. Despite this, previous work typically evaluated summary outcomes (e.g., mean change) that can mask important variation, particularly the distribution of individuals who lose or gain weight or whose weight remains stable. Such approaches may miss associations between neighborhood deprivation and weight change important to informing interventions for weight management.

In the present study, we examined associations between neighborhood deprivation and 3-year BMI change in two distinct ways. First, we assessed whether the association was negative or positive by specifying BMI change as a continuous variable. Second, we allowed for the possibility that neighborhood deprivation may have been associated with BMI loss, gain, or both by examining its association with substantive BMI loss or gain relative to maintaining a stable BMI.

We used data from an ethnically diverse cohort of adults with type 2 diabetes in a managed-care setting. Understanding determinants of BMI change is important among adults with diabetes. Weight loss often is recommended because most are overweight or obese. Weight loss among adults with diabetes improves glycemic control, lowers blood pressure, and reduces mortality risk and health-care costs (12–16). Weight gain is associated with above-goal A_{1c} and blood pressure,

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suggesting that maintaining a stable weight is an important secondary goal (17).

RESEARCH DESIGN AND METHODS

Data source

Data come from the Kaiser Permanente Northern California (KPNC) Diabetes Study of Northern California (DISTANCE), a survey completed from 2005 to 2007 by 20,188 plan members with diabetes. KPNC is a large integrated health-care system that provides comprehensive services to >3 million members. The sociodemographic characteristics of members are generally representative of the regional population, although the very poor and very wealthy are slightly underrepresented (18,19). Participants in DISTANCE come from the KPNC Diabetes Registry, which included 174,064 members at the time of sampling.

Details on DISTANCE methods have been described previously (20). In brief, DISTANCE is a survey cohort study that assesses a range of social and behavioral factors hypothesized to be associated with diabetes-related outcomes (20). The survey was based on a random sample (n = 40,735) of the registry stratified by race/ethnicity, with approximately equal samples of African Americans, Chinese, Filipinos, Latinos, and non-Hispanic whites (the region's largest ethnic groups). The response rate was 62% of eligible respondents and those survey administrators were able to contact.

Consistent with DISTANCE aims around identifying social disparities in diabetes-related outcomes, the current study examined the association between neighborhood deprivation and BMI change. The study area comprised 19 counties that contained or were adjacent to a county containing a KPNC facility and included >30 DISTANCE respondents. Of 19,804 participants with a geocodable address in the 19-county area, 18,529 were eligible for the analytic sample based on health-related criteria (type 2 diabetes; no pregnancy 9 months before baseline through 9 months after the follow-up measurement; and no evidence of procedures linked to weight loss, including bariatric surgery or lower-extremity amputation during the study). Of these, 13,609 were included in the analysis based on availability of BMI measurements, including a baseline measure (January 1, 2006–March 31, 2007) and a follow-up measure (January 1, 2009–March 31, 2010). The average length of time from baseline to follow-up was 3.4 (SD 0.5, range 1.8–4.9) years. Compared with the study sample, excluded individuals were more likely to be younger, male, non-Hispanic white or of other race/ethnicity, never married, less educated, lower income earners, or residents in more-deprived neighborhoods; differences generally were <5% between groups. Those excluded were also less likely to be taking insulin at baseline or to have started taking insulin during the study, indicating fewer visits to KPNC and, therefore, less opportunity for measurement of BMI. Excluded individuals were in worse health based on a comorbidity score (described later). Because weight loss is recommended for overweight and obese adults with diabetes, we conducted a sensitivity analysis limited to adults in these BMI categories.

BMI measures at baseline and follow-up came from height and weight recorded in KPNC electronic medical records during outpatient visits. For individuals without a clinical measure during the baseline period (~11%), we used BMI calculated from self-reported height and weight from the survey, if available. Self-reported and clinical measures at baseline were highly correlated (ρ = 0.89) in those with both measures. We included an indicator for the data source in all models. This study was approved by the institutional review boards of the Kaiser Foundation Research Institute and the University of California, San Francisco.

Variables

Outcomes. Outcomes included a continuous measure of BMI change from baseline to follow-up and a discrete measure indicating clinically substantive loss or gain of ≥7% of baseline BMI or stable BMI (stable BMI was defined as loss or gain of <7% of baseline BMI). This level of loss has been shown to improve glucose metabolism and reduce insulin resistance (21); although less research has considered the degree of weight gain and diabetes complications, we used a gain of ≥7% for ease of comparison. Hereafter, we refer to these categories as substantive BMI loss, substantive BMI gain, and stable BMI. As an example of substantive BMI change in pounds, a 5-ft 6-in woman with a BMI of 33.0 units (204 lb) at baseline would have lost a minimum of 2.31 BMI units or ~14 lb at follow-up.

Neighborhood deprivation. Based on previous research (10), we created a neighborhood deprivation index (NDI) using data from the U.S. Census Bureau, 2006–2010 American Community Survey 5-year estimates. We used the 2006–2010 American Community Survey rather than the 2000 census given proximity to baseline and follow-up BMI measures. The use of an index rather than single indicators of deprivation may more accurately capture the multidimensional nature of area socioeconomic status (10). By including variables representing numerous domains, an index is robust to problems with single variables, such as issues with comparisons over time and place and risk of incomplete conclusions. Neighborhood development affects multiple conditions, so an index may have more policy relevance than a single-variable measure. We selected the index used here because it empirically summarizes neighborhood deprivation rather than capturing distinct socioeconomic domains, as with many other summary measures; was tested in diverse geographies, such as those in the current study; and provides a standardized and reproducible measure of deprivation (6,10). It has been used to study nutrition and physical activity among girls (22), perinatal outcomes (23), and mortality (24).

The 2007 home address for each eligible participant was georeferenced using MapMarker version 11 (Pitney Bowes) software. The NDI was generated through principal components analysis of eight variables at the census tract level, including percentages of males in the neighborhood working in management and professional occupations, residents living in crowded housing (more than one person per room), households in poverty, households headed by females with dependents, households receiving public assistance, households earning <$30,000 per year, residents ≥25 years of age with less than a high school education, and residents ≥16 years of age who are unemployed. The items that comprise the NDI had excellent internal reliability (Cronbach α 0.91). Principal components analysis found one component with an eigenvalue >1 that explained 61% of the total variance in the underlying latent construct of neighborhood deprivation. The NDI was based on all census tracts in the 19-county region, regardless of whether a participant lived in the tract, ensuring that tracts were not weighted by the number of participants in the tract. Thus, all tracts contributed equally to the overall index. The measure was modeled in quartiles. We conducted a sensitivity analysis with a continuous specification of NDI as well as with squared and cubed terms (neither were significant) to test for nonlinearity. Results for the continuous specification were not substantively different from those from the quartile specification.

Covariates. Sociodemographic covariates were age, sex, race/ethnicity, education, income, employment status, nativity, and marital status. All were based on self-report.

Although living in a less-deprived neighborhood may result in intentional weight loss because of supports for a healthy lifestyle, neighborhood deprivation may cause unintentional weight change through mechanisms linked to poor health. Weight loss is usually considered advantageous to health among adults with diabetes, but unintentional weight loss may indicate deteriorating health (25). We assessed mediation by indicators of poor health associated with both unintentional weight loss and neighborhood deprivation, including evidence of cancer any time before baseline or during the study period, very poor glucose control (measured as at least two consecutive HbA_{1c} tests of >10%), and being in the highest decile of comorbidity scores at baseline and halfway through the study period (26,27) and diabetes duration. The latter two variables were included as controls for poor health not captured by other variables (25,28–30). The comorbidity score was based on validated inpatient and outpatient adjusters, which predict total health-care utilization across diagnostic clusters (27). The scores have been used previously to adjust for comorbidity (31). We also included an indicator of smoking, given its association with neighborhood deprivation and unintentional weight loss (32). We were unable to assess mediation by depression, which is associated with both unintentional weight change and neighborhood conditions (29,33), for the full sample because of data limitations. However, we conducted a sensitivity analysis that adjusted for depression at the time of the survey for a subsample of respondents.

We further adjusted for taking insulin at baseline or starting insulin during the study, given its association with unintentional weight gain and potential link to neighborhood deprivation through mechanisms of self-care and medication adherence (34). We adjusted for baseline BMI to address group-level regression to the mean (i.e., that higher or lower initial BMI might lead to greater weight loss or gain).

Analysis

Details of methods used to validate the NDI have been described elsewhere (10). We first present distributions of study variables and bivariate comparisons of baseline BMI, mean 3-year change in BMI, and substantive BMI loss or gain by sample characteristics. For bivariate comparisons, we tested for differences using χ^2 and t tests. We estimated linear regression models for 3-year BMI change and multinomial logistic regression models of substantive BMI loss or gain, with stable BMI as the reference. For both models, we first specified models that included only the NDI and number of days between BMI measures. We then adjusted for sociodemographics and baseline BMI to assess whether associations were the result of these characteristics rather than of neighborhood deprivation. Finally, we adjusted for health indicators linked to unintentional BMI change. We tested for and found no effect modification for NDI and all baseline variables in continuous and discrete models based on a P value of 0.01 to account for multiple tests; thus, we present only main effects. We specified models with expansion weighting to account for complex sampling design and modified variance estimators to account for neighborhood clustering. We imputed missing values for all baseline and interim exposure variables using multiple imputation (N = 5). Analyses were conducted in Stata 10.0 (StataCorp, College Station, TX).

RESULTS—One-third of participants (Table 1) were ≥65 years of age. One-fifth were non-Hispanic white, African American, or Latino, and one-fourth were Asian. Nearly two-thirds (58.9%) were U.S. born, and most (69.6%) were married. Most (82.5%) had a high school education or more. Forty-six percent were working, and approximately one-third (29.7%) were retired. Roughly one-half had an income of <$65,000 per year.

At baseline, 33.7% of participants were overweight and more than one-half (52.1%) were obese. On average, participants experienced minor BMI loss (−0.12, SD 3.07); however, 17.0 and 16.1% experienced substantive (≥7% of baseline) BMI loss and gain during follow-up, respectively. Missing data (imputed for multivariate models) was generally <3% for most variables with the exception of employment (12.9%) and income (14.7%).

Mean baseline BMI was higher among participants in more-deprived neighborhoods (Table 1); differences were statistically significant ($P < 0.001$) between those living in the least-deprived neighborhoods versus all other quartiles. However, there was no significant association between neighborhood deprivation and mean BMI change. In contrast, those living in more-deprived neighborhoods were somewhat more likely to have either substantive BMI loss or gain than those living in the least-deprived neighborhoods; most differences were significant at $P < 0.05$. For example, 19.9% of participants living in the most-deprived neighborhoods experienced substantive BMI loss vs. 15.0% in the least-deprived neighborhoods; similar differences were evident for substantive BMI gain in the most- versus least-deprived neighborhoods (18.0 vs. 14.1%).

Mean baseline BMI was significantly associated with most baseline and interim sociodemographic and health-related covariates. Mean BMI change was associated with several baseline and interim indicators of health status or behaviors. Older, retired, and married adults lost slightly more on average than their younger, employed, and never married counterparts. Similar patterns were evident for most cancer indicators, being in poorer health, and having a higher baseline BMI.

Most sociodemographic and health-related characteristics were also associated with substantive BMI loss or gain relative to maintaining a stable BMI. Higher baseline BMI status was associated with significantly greater likelihood of substantive BMI loss or gain.

Multivariate results

There was no significant difference in 3-year BMI change, measured continuously, by neighborhood deprivation adjusting only for number of days between BMI measures (Table 2, model 1). After adjusting for sociodemographic characteristics (Table 2, model 2), there was a significant increase in BMI for adults in the most- versus least-deprived neighborhoods (β = 0.22, P = 0.02). We further adjusted for health indicators linked to unintentional weight change and found no appreciable differences from the sociodemographic model (data not shown).

Adults in all three of the more-deprived neighborhood quartiles were

Table 1—*Characteristics of study participants, KPNC DISTANCE study, 2007–2008* (n = *13,609*)[a]

	Percent (*n*)	Mean baseline BMI (SD)	Mean change in BMI (SD)	Lost ≥7% of baseline BMI (%)[b]	Gained ≥7% of baseline BMI (%)[c]
All adults		31.5 (6.8)	−0.12 (3.07)	17.0	16.1
NDI					
Q1 (ref least deprived)	20.8 (2,833)	30.4 (0.12)	−0.16 (0.05)	15.0	14.1
Q2	28.3 (3,852)	31.1 (0.11)***	−0.09 (0.05)	16.0	16.1*
Q3	29.4 (4,000)	31.6 (0.11)***	−0.10 (0.05)	17.1**	16.1**
Q4 (most deprived)	21.5 (2,924)	32.9 (0.13)***	−0.15 (0.07)	19.9***	18.0***
Individual-level sociodemographic characteristics					
Age					
<45 years (ref)	7.8 (1,057)	34.3 (0.24)	0.09 (0.11)	15.5	18.5
45–64 years	57.5 (7,826)	32.1 (0.08)***	0.04 (0.04)	15.5	17.8
≥65 years	34.7 (4,726)	29.9 (0.09)***	−0.43 (0.04)***	19.7*	12.7***
Sex					
Female (ref)	50.1 (6,815)	32.4 (0.09)	−0.09 (0.04)	18.9	18.0
Male	49.9 (6,794)	30.6 (0.07)***	−0.15 (0.03)	15.0***	14.2***
Ethnicity					
White (ref)	21.1 (2,876)	33.9 (0.14)	−0.07 (0.06)	17.0	16.6
African American	17.3 (2,359)	33.7 (0.15)	−0.24 (0.07)	19.8**	16.9
Latino	18.5 (2,523)	32.4 (0.12)***	−0.12 (0.06)	18.1	17.2
Asian	28.4 (3,860)	27.5 (0.08)***	−0.11 (0.04)	14.2***	13.7***
Other, unknown	11.5 (1,571)	32.4 (0.17)***	−0.03 (0.08)	17.4	17.4
Nativity					
Foreign born (ref)	38.3 (5,209)	28.6 (0.07)	−0.10 (0.04)	14.9	14.5
U.S. born	58.9 (8,021)	33.4 (0.08)***	−0.12 (0.04)	18.1***	17.0***
Marital status					
Married/living together (ref)	69.6 (9,472)	31.1 (0.07)	−0.15 (0.03)	16.2	14.8
Divorced/separated/widowed	19.3 (2,620)	32.1 (0.14)***	−0.14 (0.07)	19.2***	18.7***
Never married	7.8 (1,065)	34.0 (0.25)***	0.25 (0.12)***	17.0	20.5***
Education					
Less than high school (ref)	15.5 (2,103)	31.2 (0.13)	−0.16 (0.07)	19.1	17.3
GED/high school/technical school	41.3 (5,617)	32.4 (0.09)***	−0.13 (0.04)	18.2	16.6
Associate's degree/some college	11.4 (1,548)	32.5 (0.18)***	−0.15 (0.08)	16.7*	16.6
College graduate	20.4 (2,779)	29.9 (0.12)***	0.00 (0.05)	13.3***	15.2**
Postgraduate	9.5 (1,287)	30.4 (0.18)***	−0.23 (0.08)	15.6**	12.7***
Employment status					
Employed (ref)	46.3 (6,301)	32.0 (0.09)	0.03 (0.04)	14.8	16.9
Not currently working but not retired	11.1 (1,512)	33.0 (0.20)***	−0.09 (0.09)	19.7***	19.9***
Retired	29.7 (4,036)	30.7 (0.10)***	−0.31 (0.05)***	18.8***	14.0**
Annual household income					
$0–$9,999 (ref)	4.6 (623)	31.0 (0.29)	−0.30 (0.13)	22.0	16.4
$10,000–$24,999	11.1 (1,516)	31.4 (0.18)	−0.34 (0.08)	21.4	15.6
$25,000–$34,999	10.0 (1,362)	31.4 (0.19)	−0.06 (0.09)	17.0**	17.1
$35,000–$49,000	14.3 (1,950)	32.1 (0.16)***	−0.13 (0.07)	17.9*	16.4
$50,000–$64,999	11.9 (1,621)	32.3 (0.18)***	0.03 (0.08)*	15.9**	17.3
≥$65,000	33.4 (4,541)	30.1 (0.14)*	−0.03 (0.04)*	13.8***	15.2
Individual-level health status and behaviors					
Duration of diabetes					
Diagnosed ≤5 years from survey date (ref)	34.0 (4,629)	31.8 (0.10)	−0.19 (0.04)	16.7	17.0
Diagnosed >5 years from survey date	65.5 (8,907)	31.4 (0.07)***	−0.08 (0.03)	17.5	14.4***
Taking insulin at baseline					

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Table 1—*Continued*

	Percent (n)	Mean baseline BMI (SD)	Mean change in BMI (SD)	Lost ≥7% of baseline BMI (%)[b]	Gained ≥7% of baseline BMI (%)[c]
Yes (ref)	18.2 (2,474)	33.2 (0.15)	0.05 (0.07)	17.7	21.2
No	81.8 (11,135)	31.1 (0.07)***	−0.16 (0.03)**	16.8**	15.0***
Started insulin during study period					
Yes (ref)	14.1 (1,917)	32.3 (0.16)	0.66 (0.07)	11.0	25.9
No	85.9 (11,692)	31.4 (0.06)***	−0.25 (0.03)***	17.9***	14.5***
Had two or more consecutive tests of HbA_{1c} ≥10% during study period					
No (ref)	89.2 (12,139)	31.4 (0.06)	−0.12 (0.03)	16.6	15.5
Yes	9.7 (1,320)	32.7 (0.20)***	−0.01 (0.10)	19.9***	21.7***
Baseline inpatient utilization adjuster					
Deciles 1–9 (ref)	90.7 (12,343)	31.3 (0.06)	−0.07 (0.03)	16.1	15.7
Decile 10 (highest cost)	8.6 (1,175)	33.2 (0.22)***	−0.61 (0.11)***	25.9***	17.1**
Interim inpatient utilization adjuster					
Deciles 1–9 (ref)	90.8 (12,361)	31.4 (0.06)	−0.08 (0.03)	16.2	15.9
Decile 10 (highest cost)	8.7 (1,183)	33.0 (0.21)***	−0.51 (0.12)***	24.9***	18.3***
Baseline outpatient utilization adjuster					
Deciles 1–9 (ref)	90.0 (12,249)	31.3 (0.06)	−0.08 (0.03)	16.1	15.7
Decile 10 (highest cost)	9.1 (1,241)	33.7 (0.21)***	−0.49 (0.11)***	25.4***	17.7**
Interim outpatient utilization adjuster					
Deciles 1–9 (ref)	88.7 (12,071)	31.3 (0.06)	−0.08 (0.03)	16.1	15.6
Decile 10 (highest cost)	9.5 (1,297)	33.5 (0.21)***	−0.38 (0.11)**	24.8***	20.4***
Cancer					
None (ref)	89.5 (12,183)	31.6 (0.06)	−0.08 (0.03)	16.2	16.2
Closest tumor >3 years before baseline	5.1 (693)	31.2 (0.25)	−0.36 (0.12)*	22.4***	15.7
Closest tumor <3 years before baseline	2.3 (309)	30.8 (0.36)*	−0.31 (0.17)	16.8	13.6
Closest tumor after baseline/before last BMI measure	3.0 (411)	31.2 (0.34)	−0.75 (0.17)***	29.7***	13.9
Cancer but time frame unknown	0.1 (13)	32.2 (1.77)	−0.55 (1.02)	30.8	23.1
Smoking status					
Nonsmoker or former smoker (ref)	80.6 (10,965)	31.7 (0.07)	−0.11 (0.03)	16.7	15.8
Current smoker	6.5 (881)	31.8 (0.22)*	−0.03 (0.11)	18.5*	19.9***
BMI					
Baseline BMI					
Normal (<25.0) (ref)	14.2 (1,933)	22.9 (0.04)	0.43 (0.05)	10.3	20.2
Overweight (25.0–<30.0)	33.7 (4,588)	27.5 (0.02)***	0.03 (0.04)***	14.8***	15.2***
Obese I (30.0–<35.0)	26.4 (3,588)	32.3 (0.02)***	−0.18 (0.05)***	18.5***	15.5**
Obese II (35.0–<40.0)	15.4 (2,096)	37.3 (0.03)***	−0.34 (0.08)***	21.4***	15.7
Obese III (≥40.0)	10.3 (1,404)	45.6 (0.15)***	−0.85 (0.01)***	22.7***	15.5

GED, general educational development. [a]Tests of statistical significance are for BMI outcomes versus the reference group. [b]Tests of statistical significance are for comparison versus reference group for lost ≥7% of baseline BMI versus maintaining a stable BMI over an ~3-year period. [c]Tests of statistical significance are for comparison versus reference group for gained ≥7% of baseline BMI versus maintaining a stable BMI over an ~3-year period. *$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

more likely to experience substantive BMI loss or gain relative to those in the least-deprived quartile (Table 3). After adjusting for sociodemographic covariates (Table 3, model 2), a significant difference remained between adults in the least-deprived neighborhood and those in all three more-deprived neighborhood quartiles for substantive BMI loss (Q2 relative risk ratio [RRR] 1.19, 95% CI 1.00–1.41; Q3 1.20, 1.02–1.42; Q4 1.30, 1.08–1.55) or substantive BMI gain (Q2 1.25, 1.04–1.49; Q3 1.24, 1.04–1.49; Q4 1.45, 1.20–1.75). Results were similar after adjustment for health indicators linked to unintentional weight change (data not shown).

Results were also similar when the analysis was limited to overweight and obese participants and those with depression (data not shown). This consistency of results indicates internal reliability of the association between NDI and outcomes.

CONCLUSIONS—In a diverse population of adults with type 2 diabetes in a managed-care setting, the NDI was modestly associated with both substantive BMI loss and gain (≥7% loss or gain of baseline BMI) over an ~3-year period. For example, 18.0% of adults in the most-deprived quartile of neighborhood deprivation experienced substantive BMI gain vs. 16.1% in Q2 and Q3 and 14.1% in Q1 (least deprived). Similarly modest differences by NDI quartile were observed

Table 2—*Coefficients for 3-year change in BMI in adults with diabetes, KPNC, 2006–2010*[a]

	Model 1		Model 2	
	B	SE	B	SE
NDI quartile (ref Q1, least deprived)				
Q2	−0.09	0.09	0.10	0.08
Q3	0.07	0.09	0.10	0.09
Q4 (most deprived)	0.14	0.09	0.22*	0.10
Individual-level sociodemographic characteristics				
Age			−0.04***	0.00
Male (ref female)			−0.24***	0.07
Race/ethnicity (ref white)				
African American			−0.31**	0.10
Latino			−0.24*	0.10
Asian			−0.51***	0.10
Other			−0.17	0.11
Nativity (ref foreign born)				
U.S. born			0.16	0.09
Marital status (ref married/living together)				
Divorced/separated/widowed			0.16	0.09
Never married			0.40*	0.16
Education (ref less than high school)				
GED/high school/technical school			−0.04	0.09
Associate's degree/some college			−0.10	0.13
College graduate			−0.01	0.11
Postgraduate			−0.19	0.14
Annual household income (ref $0–$9,999)				
$10,000–$24,999			−0.01	0.17
$25,000–$34,999			0.15	0.17
$35,000–$49,000			0.11	0.17
$50,000–$64,999			0.23	0.17
≥$65,000			0.20	0.16
Employment status (ref employed)				
Not currently working but not retired			0.04	0.12
Retired			−0.05	0.09
Baseline BMI			−0.09***	0.01
Constant	−0.15	0.24	4.76***	0.53

GED, general educational development. [a]All models are adjusted for number of days between baseline and follow-up BMI measures. *$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

for substantive BMI loss. After adjustment for sociodemographic characteristics and health indicators associated with unintentional weight change, significant differences remained between the more-deprived quartiles and the least-deprived quartile for substantive BMI loss and gain.

Neighborhood deprivation was positively associated with BMI change measured as a simple difference between baseline and follow-up. We tested for and found no substantive effect modification by sociodemographic variables, health behavioral or health status variables, duration of diabetes, or baseline BMI; more research is needed to assess other characteristics not measured in this study.

The results highlight the importance of evaluating segmented relationships (allowing for simultaneous associations with both gain and loss) as well as continuous or repeated measures of weight change with regard to neighborhood deprivation in future studies. Failure to do so may partly explain the mixed results from the limited number of longitudinal studies of weight change to date, with one investigation finding no association between neighborhood socioeconomic status and repeated BMI measures and two others finding positive associations with a continuous measure of difference (6–8). Studies that assess only clinically substantive weight loss measured as a discrete variable may similarly miss important relationships between weight gain and neighborhood characteristics.

Investigations of weight trajectories among adults with diabetes confirmed that these individuals experience a range of outcomes from weight loss to gain, stability, and fluctuations, with gain followed by loss and vice versa (11,17). Although we did not examine fluctuations because of the short follow-up time, a more complex approach may capture possible shape-variant rather than linear relationships between neighborhood deprivation and weight change over time and provide guidance for practice and policy. Given the mixed results in longitudinal research on neighborhood deprivation and weight change, such approaches may be important to assessing implications of moving to deprived neighborhoods for BMI change as well as associated policy implications.

In fact, weight fluctuation may explain the observed association between neighborhood deprivation and either substantive BMI loss or gain. Adults with diabetes living in more-deprived neighborhoods may be subject to greater fluctuation than adults in less-deprived settings; for example, they may be more likely to lose weight given their initially higher average BMIs but have more difficulty maintaining weight loss because of an environment unsupportive of weight maintenance [i.e., with poorer walkability; fewer places to exercise (1); limited availability of fruits and vegetables (2); and greater exposure to environmental stressors, such as noise and violence (3,4)], which is linked to weight gain. For similar reasons, some residents may also be more likely to gain, followed by a greater need to lose weight. The net loss observed among residents in more-deprived neighborhoods may be capturing a period of loss in a longer cycle of weight fluctuation. The same may be true of BMI gain, although notably, this association is consistent with research suggesting that conditions in more-deprived neighborhoods are not conducive to avoiding gain (2,4,35–37). Research that captures an even wider spectrum of patterns of BMI change than considered here may be useful in understanding associations with neighborhood conditions. This may be especially important for adults with weight-related conditions like diabetes, most of whom are engaged in a long-term process of weight management in an attempt to delay disease complications (14).

Table 3—*RRRs from multinomial logistic regression models of 3-year loss or gain of ≥7% of baseline BMI in adults with diabetes, KPNC, 2006–2010*[a]

	BMI loss		BMI gain	
	Model 1	Model 2	Model 1	Model 2
NDI quartile (ref Q1, least deprived)				
Q2	1.26 (1.07–1.48)**	1.19 (1.01–1.41)*	1.32 (1.11–1.57)**	1.25 (1.04–1.49)*
Q3	1.34 (1.14–1.56)***	1.20 (1.02–1.42)*	1.37 (1.15–1.62)***	1.24 (1.04–1.49)*
Q4 (most deprived)	1.57 (1.33–1.85)***	1.30 (1.08–1.55)**	1.65 (1.39–1.97)***	1.45 (1.20–1.75)***
Individual-level sociodemographic characteristics				
Age		1.02 (1.01–1.02)***		0.98 (0.98–0.99)***
Male (ref female)		0.87 (0.77–0.98)*		0.74 (0.66–0.83)***
Race/ethnicity (ref white)				
African American		1.05 (0.90–1.23)		0.85 (0.71–1.00)
Latino		1.08 (0.93–1.26)		0.93 (0.78–1.10)
Asian		1.12 (0.95–1.33)		0.78 (0.65–0.94)**
Other		1.07 (0.90–1.27)		0.95 (0.79–1.14)
Nativity (ref foreign born)				
U.S. born		1.11 (0.96–1.28)		1.26 (1.08–1.46)**
Marital status (ref married/living together)				
Divorced/separated/widowed		0.97 (0.83–1.12)		1.34 (1.15–1.57)***
Never married		1.13 (0.92–1.41)		1.39 (1.14–1.71)**
Education (ref less than high school)				
GED/high school/technical school		1.03 (0.87–1.21)		0.86 (0.73–1.02)
Associate's degree/some college		0.94 (0.76–1.17)		0.93 (0.74–1.16)
College graduate		0.87 (0.71–1.08)		0.80 (0.65–0.99)*
Postgraduate		0.98 (0.77–1.24)		0.68 (0.52–0.88)**
Annual household income (ref $0–$9,999)				
$10,000–$24,999		1.07 (0.83–1.39)		1.08 (0.80–1.46)
$25,000–$34,999		0.89 (0.69–1.16)		1.11 (0.83–1.48)
$35,000–$49,000		0.93 (0.72–1.19)		1.11 (0.82–1.50)
$50,000–$64,999		0.87 (0.65–1.15)		1.22 (0.89–1.67)
≥$65,000		0.77 (0.60–0.99)*		1.12 (0.83–1.52)
Employment status (ref employed)				
Not currently working but not retired		1.06 (0.89–1.27)		1.19 (0.99–1.44)
Retired		0.99 (0.84–1.17)		0.93 (0.79–1.10)
Baseline BMI		1.04 (1.03–1.05)***		0.97 (0.96–0.98)***

Data are RRR (95% CI). GED, general educational development. [a]All models are adjusted for number of days between baseline and follow-up BMI measures. *$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

The observed association between greater neighborhood deprivation and substantive BMI loss or gain may instead be a result of mechanisms related to poor health; that is, BMI change may have been unintentional. For example, neighborhood deprivation is associated with a number of health conditions associated with unintentional weight change (either directly or through medications), such as depression and disability, as well as with health behaviors linked to unintentional weight change, like smoking. We adjusted for health conditions, behaviors, and metabolic status associated with unintentional weight change, but these controls may have been inadequate. Further, our control for baseline BMI may not have fully adjusted for regression to the mean among adults living in more-deprived neighborhoods, who had higher initial body weight. We adjusted for higher baseline BMI, which may be a proxy for greater motivation to lose weight, but we were unable to adjust directly for motivation to lose weight, which could potentially disproportionately affect residents in more-deprived settings. Additional research is needed to identify whether weight loss in adults with diabetes in relation to neighborhood deprivation is intentional (motivation to lose weight) or unintentional (health conditions) as well as to identify physiological pathways to weight change.

This analysis was subject to additional limitations. The sample was drawn from a managed-care population of adults with diabetes; therefore, external validity may be limited to others in a similar managed-care setting. Although neighborhood deprivation and BMI may differ for managed-care members with diabetes compared with uninsured patients or those insured by different organizations, observed exposure-outcome associations are typically much less variable across populations. The relatively low response rate of 62% may have resulted in selection bias linked to neighborhood deprivation and may mean that patterns of BMI across neighborhoods are somewhat biased, but it is less likely that associations were biased. Similarly, survey respondents in more-deprived neighborhoods were more likely to be excluded from the sample because of missing BMI measurements at baseline or follow-up, which may have also resulted in selection bias, although we assume it to be minor. Census tracts, used as a proxy for neighborhoods, may not capture neighborhood boundaries in ways that are most meaningful for residents or for health. The findings based on census tracts likely underestimate true associations related to contextually defined (real) neighborhoods that have substantive deprivation boundaries and transition zones.

Overall, the findings point to the importance of evaluating segmented relationships (allowing for simultaneous associations with both gain and loss) in longitudinal studies of neighborhood deprivation and weight change. Failure to do so may result in missing important associations. Evaluating segmented relationships may be particularly key for studies involving patients with diabetes in whom both weight loss and weight gain, intentional and unintentional, have important health implications (12–17,38).

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P.J.S. conducted the data analysis and wrote the manuscript. B.A.L. participated in study design, supervised the data analysis, and reviewed and edited the manuscript. E.M.W. prepared the data sets, conducted the data analysis, and reviewed and edited the manuscript. H.H.M., N.E.A., D.S., and A.J.K. contributed to the study design and interpretation of findings and reviewed and edited the manuscript. A.J.K. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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