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Original Contribution

Associations of Residential Socioeconomic, Food, and Built Environments With Glycemic Control in Persons With Diabetes in New York City From 2007–2013

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In the present study, we examined the longitudinal associations between residential environmental factors and glycemic control in 182,756 adults with diabetes in New York City from 2007 to 2013. Glycemic control was defined as a hemoglobin A1c (HbA1c) level less than 7%. We constructed residential-level measures and performed principle component analysis to formulate a residential composite score. On the basis of this score, we divided residential areas into quintiles, with the lowest and highest quintiles reflecting the least and most advantaged residential environments, respectively. Several residential-level environmental characteristics, including more advantaged socioeconomic conditions, greater ratio of healthy food outlets to unhealthy food outlets, and residential walkability were associated with increased glycemic control. Individuals who lived continuously in the most advantaged residential areas took less time to achieve glycemic control compared with the individuals who lived continuously in the least advantaged residential areas (9.9 vs. 11.5 months). Moving from less advantaged residential areas to more advantaged residential areas was related to improved diabetes control (decrease in HbA1c = 0.40%, 95% confidence interval: 0.22, 0.55), whereas moving from more advantaged residential areas to less advantaged residential areas was related to worsening diabetes control (increase in HbA1c = 0.33%, 95% confidence interval: 0.24, 0.44). These results show that residential areas with greater resources to support healthy food and residential walkability are associated with improved glycemic control in persons with diabetes.

built environment; diabetes mellitus; food environment; glycemic control; residential environment; socioeconomic factors

Abbreviations: CI, confidence interval; BMI, body mass index; HbA1c, hemoglobin A1c; NYC, New York City; OR, odds ratio.

In several epidemiologic studies, investigators have examined residential environments and related health outcomes, and there is evidence that better access to high-quality residential resources is associated with better health, as well as decreased disease prevalence and incidence (1–5). Results from these studies suggest that modifying residential environments may improve population health and reduce health disparities by increasing health behaviors and minimizing unhealthy exposures (2, 6).

Research has explored this concept (7–9), and several mechanisms for this relationship have been proposed (10). Residential socioeconomic disadvantage, as measured by household income, poverty level and racial composition, has been found to be associated with higher body mass index (BMI) (11–13), cardiovascular disease (10), and hypertension (11), which are independent of individual-level characteristics. Regarding food environment, several studies have found that greater residential availability of healthy food options is associated with healthier diet (5, 14, 15) and lower obesity (11, 16–19), whereas higher density of outlets selling poorer quality foods (e.g., fast food restaurants and small grocery stores) is associated with increased weight (11, 13). With respect to the built environment, residential walkability and high density of mixed residential and commercial units has been associated with higher levels of walking (20–23) and decreased weight (16, 24); access to parks and recreational facilities has also been associated with higher levels of physical activity (25–28).

Research on the influence of the residential environment on persons with diabetes mellitus is limited. A small amount of cross-sectional and longitudinal evidence exist that show that residential socioeconomic status, as well as availability of healthy food, physical activity resources, and walking environments, have statistically significant associations with the incidence and prevalence of diabetes (2, 23). It is unclear, however, whether residential environments directly contribute to diabetes control in persons with diabetes. To our knowledge, no study has prospectively evaluated whether the cumulative number of exposures to specific residential features is associated with glycemic control in persons with diabetes in a large multiracial, multiethnic cohort.

The present study was conducted to determine whether residential-level socioeconomic, food, and built environment factors were associated with glycemic control in a population of adults with diabetes in New York City (NYC) over a 7-year period. We hypothesized that residential resources that supported high-quality environments would be associated with better glycemic control, as measured by hemoglobin A1c (HbA1c). Specifically, we aimed to assess: 1) associations between residential-level environmental factors and glycemic control; 2) associations between residential-level environmental factors on achievement of, and failure to maintain glycemic control; 3) residential stability and longitudinal influence of continuously living in 1 residential area on glycemic control; and 4) residential mobility and the longitudinal influence of moving between residential areas on glycemic control.

METHODS

Study population

We utilized data from the NYC HbA1c Registry (referred to here as the Registry) (29). In 2006, the NYC Department of Health and Mental Hygiene implemented mandatory reporting of HbA1c tests to the Registry from NYC residents, which enabled public health surveillance of diabetes trends in the area. The Registry has limited data accompanying HbA1c test results (e.g., demographic information) and does not include any clinical history to confirm diabetes diagnosis. Consistent with the diagnostic criteria of the American Diabetes Association (30), we defined diabetes as the reporting of at least 2 HbA1c tests with a value of 6.5% or greater since the inception of the Registry.

The study included NYC residents aged 18 years or older with diabetes who reported at least 1 HbA1c test every year in the Registry between January 1, 2007, and December 31, 2013. Each study aim examined a different registrant cohort. Aim 1 and aim 2 included all persons who had at least 1 HbA1c test every year between 2007–2009 (defined as time 1 period) and who stayed in their place of residence throughout the 3-year time 1 period. Aim 3, which measured residential stability, examined persons included in aim 1 and aim 2 who stayed in their original place of residence after the end of time 1 period and who had yearly testing throughout a 4-year time 2 period (2010–2013). Aim 4, which measured residential mobility, examined persons included in aim 1 and aim 2 who moved to and stayed in a new residential area after the end of time 1 period and who had yearly testing throughout the 4-year time 2 period. The comparison group for residential mobility was the cohort examined for aim 3.

Variables

For aim 1 and aim 2, the primary outcome was glycemic control, defined by the American Diabetes Association's guidelines (30) as an HbA1c level less than 7% across all HbA1c tests. As a sensitivity analysis, we examined a less stringent glycemic control target (HbA1c <8%). For aims 3 and 4, the outcome of interest was mean HbA1c value across all HbA1c tests for the period of interest. The residential-level measures processed for the current study was guided by previous literature and has been described extensively (16, 31–33). A detailed description is provided in the Web Appendix 1 (available at https://academic.oup.com/aje). Briefly, we defined residential areas by zip code ($n = 164$), and constructed 16 residential-level measures by combining several proprietary and public use geo-spatial data sets and included measures of socioeconomic, food, and built environments. These measures were then matched to data from the Registry using a unique individual zip code feature key identification. Socioeconomic environment variables were constructed using data from the 2000 US Census summary file 3 (34), which include race/ethnic composition, median household income, education attainment, area-based neighborhood poverty level, proportion of population who are linguistically isolated, and homicide crime. Food environment measures were derived from 2005 data purchased from Dun & Bradstreet (Short Hills, New Jersey), which include business name, geocoded location, and detailed Standard Industrial Classification industry codes for food establishments. As described previously (16), we first identified types of food outlets by Standard Industrial Classification code numbers and business name searches, and then grouped them into categories that were hypothesized to provide BMI-healthy or BMI-unhealthy food, with a neutral category for outlets whose classification was uncertain. Built environment variables constructed for the present study included a measure of residential walkability (a co-distribution of residential and commercial land use mix) using the 2005 Primary Land Use Tax Lot Output (35), a parcel-level data set available from the NYC Department of City Planning. Other built environment measures included proportion of park and green space area, as well as proportion of outdoor open space and recreational areas per zip code, determined by using the 2006 data from the NYC Department of Parks and Recreation boundary shapefile and the NYC Department of City Planning. Individual-level variables included age at baseline (age at the first HbA1c test in 2007), sex, frequency of HbA1c testing, duration of follow-up (months) and average time interval between HbA1c testing (months).

Statistical approach

To aid in interpreting the magnitude of associations and to allow for comparison of relative changes that were associated with a 1 standard deviation increase, the results were examined as transformed residential variables using standardized z scores. Therefore, changes of continuous independent variables were measured as 1-unit offsets from the standard deviation.

Correlation analyses were performed for all residential-level environmental variables to measure the strength and direction of a linear relationship between these variables. As is often found with census data, several of these variables were highly and significantly correlated (Web Table 1). Given the high degree of correlation amongst residential-level environmental variables, and considering the problem of multicollinearity that would result from analyzing these measures simultaneously in multivariate models, we performed principle component analysis. In total, 3 factors extracted in the principle component analysis explained 82% of the variation in the data. Factor 1 represented a mix of residential socioeconomic and BMI-unhealthy food variables, whereas factor 2 reflected residential social variables, and factor 3 represented availability and accessibility of BMI-healthy and BMI-neutral food outlets, as well as residential walkability (Web Table 2). These factors were not significantly correlated with one another (for factor 1 vs. factor 2, correlation coefficient = 0.03, $P = 0.70$; for factor 1 vs. factor 3, correlation coefficient = 0.09, $P = 0.26$; for factor 2 vs. factor 3, correlation coefficient = 0.13, $P = 0.10$). Because a high score for both factor 1 and factor 2 reflected residential disadvantage and a high score for factor 3 reflected residential advantage, factor 1 and factor 2 were rescaled accordingly such that a high score represented a more advantaged residential environment. We then combined the components of the significant factors to formulate a residential composite score (an overall measure of residential environment) by summing the variable scores within each factor and then across factors. On the basis of this composite score, we divided residential areas into quintiles. The first (lowest) quintile reflects the least advantaged residential environments and the fifth (highest) reflects the most advantaged environments.

In the present study, a multilevel mixed modeling framework with the following hierarchical structure was applied: longitudinal repeated HbA1c measurements (level 1) were nested within individuals (level 2), which were nested within residential areas (level 3). Specifically, generalized linear mixed models with a binary distribution for residual errors and logit link function were used to estimate odds ratios and 95% confidence intervals to assess the associations between residential-level environmental factors and glycemic control (aim 1). The intra-cluster correlation coefficient derived from the model was used to assess the variance within and between residential areas. Conditional Cox proportional hazards models with robust sandwich estimates of the covariance matrix were used to conduct time-to-event analysis and estimate hazard ratios and 95% confidence intervals to assess the association between residential-level environmental factors and achievement of glycemic control (aim 2). Time-to-event analysis was conducted in 2 ways: 1) time to achieve glycemic control for individuals with HbA1c 7% or greater at baseline (first HbA1c test in 2007), and 2) time to failure to maintain glycemic control for individuals with HbA1c less than 7% at baseline. As individuals had many repeated HbA1c measurements at different time points (initial and all subsequent HbA1c tests), we assumed that the hazard varied as a function of time since the individual's last event. Finally, random coefficient linear mixed models with continuous outcomes and random intercept and slope (time) were used to examine 1) residential stability and changes in mean HbA1c values for individuals who stayed in their original residential areas (aim 3), and 2) residential mobility comparing positive and negative change in mean HbA1c slope between individuals who moved from 1 residential area to another across the residential environment composite score (aim 4).

The multivariate models were further adjusted for age, sex, frequency of HbA1c testing, duration of follow-up (months), average time interval between HbA1c testing (months) and zip-code level number of total population. The fitness of models and their covariance structure were assessed using −2 Log likelihood test, as well as Akaike's and Bayesian information criterion statistics. We evaluated the proportional hazard assumption of Cox models by plotting Schoenfeld residuals against time. Descriptive statistics were generated using mean (standard deviation) and median (25%–75% interquartile range) for continuous variables and proportions for categorical variables. All statistical tests were 2-sided, with a threshold for significance of $P < 0.05$. All descriptive and comparative analyses were conducted using SAS, version 9.2 (SAS Institute, Inc., Cary, North Carolina). The research protocol of the present study was reviewed and approved by the NYC Department of Health and Mental Hygiene institutional review board.

RESULTS

Description of residential areas

In the present study, the least advantaged residential areas (first quintile of the residential environment composite score) were found to be more likely to have a larger number of residents, higher proportion of racial and ethnic minorities, and higher proportion of socioeconomic disadvantage compared with the most advantaged (fifth quintile) residential areas (Table 1). Compared with the most advantaged areas, the least advantaged areas also had lower land-use mix, residential walkability, and numbers of healthy and neutral food outlets. There were no statistically significant differences between the 2 types of residential areas with regard to the number of unhealthy food outlets, percentage of residential area parks and green space, and proportion of outdoor recreational resources.

Demographic characteristics of individuals

The 182,756 adults included in the study had a mean age of 64 years and a mean HbA1c of 7.7%. The median number of HbA1c tests over the 3-year period was 6 and the median average time interval between HbA1c tests was 4.3 months (Table 2).

Associations between residential environments and glycemic control

Age, sex, socioeconomic environment variables (all except linguistic isolation), BMI-healthy, neutral and unhealthy food environment ratios, and residential walkability were significantly associated with glycemic control (Table 3). In the multivariate analysis, all 3 residential environment factor scores independently (odds ratio (OR) = 1.30, 95% confidence interval (CI): 1.28, 1.33; OR = 1.40, 95% CI: 1.38, 1.42; OR = 1.08, 95% CI: 1.06, 1.11) and the summary residential environment composite score (OR = 1.57, 95% CI: 1.54, 1.61) were significantly associated with glycemic control. The odds of glycemic

Table 1. Operational Definitions and Distribution of Residential Environment Variables, New York City, 2007–2009

Residential Environment Variable	Overall, mean (SD)	Quintile[a]		*P* Value
		1, mean (SD)	5, mean (SD)	
Socioeconomic environment[b]				
Total population, no.	48,752 (25,414)	56,461 (22,851)	39,038 (23,415)	<0.001
White population, %	47.4 (28.0)	18.7 (14.0)	74.4 (13.2)	<0.001
Black or African-American population, %	25.5 (28.1)	52.1 (27.0)	5.4 (5.8)	<0.001
Hispanic or Latino population, %	24.4 (19.9)	35.6 (24.4)	12.7 (7.2)	<0.001
Population with income below 100% of the federal poverty line, %	19.4 (11.3)	29.6 (11.0)	11.0 (5.6)	<0.001
Median household income	41,491 (16,098)	28,765 (10,775)	56,572 (14,635)	<0.001
Linguistically isolated, %	13.3 (9.4)	14.1 (9.3)	9.1 (6.8)	0.01
College graduate, %	32.6 (17.7)	18.8 (6.2)	52.4 (18.4)	<0.001
High school graduate, %	24.9 (7.8)	26.8 (4.0)	18.9 (10.5)	<0.001
Less than high school graduate, %	26.8 (13.0)	37.7 (10.3)	14.4 (8.2)	<0.001
Median number of homicides	0.9 (1.2)	2.0 (1.4)	0.3 (0.4)	<0.001
Food environment[c]				
BMI-healthy food outlets	10.6 (7.7)	9.5 (6.6)	13.1 (8.6)	0.02
BMI-neutral food outlets	100.7 (57.3)	107.5 (52.1)	186.8 (135.3)	<0.001
BMI-unhealthy food outlets	120.5 (97.6)	81.6 (39.0)	97.5 (55.3)	0.28
Built environment[d]				
Land-use mix index	0.5 (0.2)	0.4 (0.2)	0.6 (0.3)	<0.001
Residential area that is covered by all parks, %	10.2 (11.6)	10.3 (10.8)	9.9 (15.0)	0.97
Open space and outdoor recreational areas, %	11.1 (13.3)	9.0 (10.3)	11.0 (15.9)	0.26
Residential environment factor score				
1[e]	0.0 (1.0)	−0.5 (1.0)	0.8 (0.7)	<0.001
2[f]	0.0 (1.0)	−1.0 (1.0)	0.6 (0.3)	<0.001
3[g]	0.0 (1.0)	−0.3 (0.9)	0.6 (1.1)	<0.001
Residential environment composite score[h]	0.0 (1.0)	−1.1 (0.4)	1.2 (0.8)	<0.001

Abbreviations: BMI, body mass index; SD, standard deviation.

[a] The first quintile represents the least advantaged residential environment; the fifth quintile represents the most advantaged residential environment.

[b] Social environment variables were constructed at the zip-code level using US Census data from the year 2000. All 2000 US Census variables were calculated using variables of sample data from summary file 3 (34). Homicide variables were mined from the *New York Times* (51).

[c] Food environment measures were derived from 2005 data purchased from Dun & Bradstreet, a commercial vendor of business data. Dun & Bradstreet maintains a comprehensive database of microdata on over 11 million US business locations, which include business name, geocoded location, and detailed Standard Industrial Classification industry codes for food establishments (52). Food outlets for BMI-healthy, BMI-neutral, and BMI-unhealthy were measured using point-in polygons counts.

[d] Built environment variables constructed for the present study included a measure of residential and commercial land use mix using the Primary Land Use Tax Lot Output data (35), the percentage of open space and outdoor recreational area available from the Department of City Planning, and the percentage of park and green space area available from NYC Department of Parks and Recreation park boundary shapefile data (53).

[e] Residential environment factor score 1 is a summary score extracted from principal component analysis of the variables low proportion of Hispanic population, poverty, linguistically isolated, less than high school education, ratio of counts of BMI-unhealthy food to BMI-healthy and BMI-neutral food outlets, high proportion of neighborhood income, and college education. This score explained 47.9% of the variation of the original neighborhood variables.

[f] Residential environment factor score 2 is a summary score extracted from principal component analysis of the variables low proportion of black population, homicide crime; and high proportion of white population. This score explained 22.9% of the variation of the original neighborhood variables.

[g] Residential environment factor score 3 is a summary score extracted from principal component analysis of the variables ratio of BMI-healthy food to BMI-neutral and BMI-unhealthy food outlets, ratio of BMI-neutral food to BMI-healthy and BMI-unhealthy food outlets and neighborhood walkability. This score explained 11.0% of the variation of the original neighborhood variables.

[h] A residential socioeconomic, food and built environment composite score was created by combining the 3 components identified by principal component analysis and then divided into quintiles. This score explain a substantial amount of the variation (81.8%) of the original neighborhood variables.

Table 2. Demographic Characteristics of Individuals, New York City, 2007–2009

Characteristic	No.	%	Mean (SD)	Median (IQR)
Total	182,756			
Age, years[a]			64.1 (12.9)	64.0 (55.0–73.0)
Sex				
Female	104,197	57.0		
Male	77,842	42.6		
Unknown	717	0.4		
Average HbA1c, %			7.7 (1.8)	7.1 (6.5–8.3)
No. of tests	1,273,801			
Frequency of HbA1c testing			7.0 (3.0)	6.0 (5.0–8.0)
Duration of follow-up, months			28.1 (4.4)	28.7 (25.1–31.6)
Average time interval between HbA1c testing, months			4.8 (2.2)	4.3 (3.4–5.7)
Level of glycemic control at baseline				
HbA1c <7.0%	79,277	43.4		
HbA1c <8.0%	126,106	69.0		
Borough of residence				
Bronx	40,366	22.1		
Brooklyn	55,195	30.2		
Manhattan	25,738	14.1		
Queens	49,387	27.0		
Staten Island	12,070	6.6		
Residential environment composite score quintile[b]				
1	43,822	24.0		
2	48,712	26.7		
3	44,326	24.3		
4	28,801	15.8		
5	17,095	9.4		

Abbreviations: HbA1c, hemoglobin A1c; IQR, interquartile range; SD, standard deviation.
[a] Age at first HbA1c test in 2007.
[b] The first quintile represents the least advantaged residential environment; the fifth quintile represents the most advantaged residential environment.

control in the most advantaged residential areas was 2.59 times higher than in the least advantaged residential areas (95% CI: 2.43, 2.77). The intra-residential correlation coefficient was 0.02.

Table 4 shows the time-to-event analyses by residential environment composite score quintiles. The result indicates that among individuals with a first HbA1c test of 7% or greater, living in the most advantaged residential areas was associated with a shorter time to achieving glycemic control compared with living in the least advantaged areas (9.9 months (95% CI: 9.6, 10.1) vs. 11.5 months (95% CI: 11.4, 11.7); hazard ratio = 1.14, 95% CI: 1.12, 1.16). Among individuals with a first HbA1c test of less than 7%, living in the most advantaged residential areas was associated with a longer time to failure to maintain glycemic control compared with individuals who lived in the least advantaged areas (10.9 months (95% CI: 10.7, 11.1) vs. 9.7 months (95% CI: 9.6, 9.9); hazard ratio = 0.87, 95% CI: 0.85, 0.89).

Residential stability

Table 5 illustrates trajectories of mean HbA1c by residential environment composite score quintiles for individuals who stayed in their place of residence between 2007 and 2013. The intercept of mean HbA1c in the most advantaged residential areas was 0.44% lower than in the least advantaged areas ($P < 0.001$). Overall, the slope of mean HbA1c was fairly stable across all residential environment composite score quintiles over the 7-year study period, and ranged from clinically insignificant 0.13% in the least advantaged residential areas to −0.01% in the most advantaged areas. These results suggest that individuals who lived continuously in more advantaged residential areas had persistently lower mean HbA1c values and better diabetes control compared with the individuals who lived continuously in less advantaged residential areas.

Table 3. Longitudinal Associations Between Individual and Residential Level Variables and Glycemic Control, New York City, 2007–2009

Variable	OR	95% CI	*P* Value
Individual-level variables (models 1–2)[a]			
Age	1.83	1.80, 1.87	<0.001
Sex, male vs. female	0.93	0.90, 0.96	<0.001
Residential-level variables (models 3–18)[b]			
% White population	1.47	1.45, 1.50	<0.001
% Black or African American population	0.75	0.74, 0.76	<0.001
% Hispanic or Latino population	0.79	0.78, 0.81	<0.001
% Whose income is below 100% of the federal poverty line	0.74	0.73, 0.75	<0.001
Median household income	1.46	1.43, 1.49	<0.001
% Linguistically isolated	1.01	0.99, 1.03	0.21
% College graduate	1.51	1.47, 1.54	<0.001
% High school graduate	0.92	0.90, 0.94	<0.001
% Less than high school graduate	0.71	0.70, 0.72	<0.001
Median number of homicides	0.77	0.75, 0.78	<0.001
Ratio of BMI-healthy to BMI-neutral and BMI-unhealthy food outlets	1.09	1.07, 1.11	<0.001
Ratio of BMI-neutral to BMI-healthy and BMI-unhealthy food outlets	1.50	1.45, 1.54	<0.001
Ratio of BMI-unhealthy to BMI-healthy and BMI-neutral food outlets	0.75	0.74, 0.77	<0.001
Commercial and residential land-use mix index	1.05	1.03, 1.08	<0.001
% Residential area that is covered by all parks	0.98	0.96, 1.00	0.15
% Open space and outdoor recreational area	0.99	0.97, 1.01	0.23
Residential environment factor scores (model 19)[b]			
1	1.30	1.28, 1.33	<0.001
2	1.40	1.38, 1.42	<0.001
3	1.08	1.06, 1.11	<0.001
Residential environment composite score (model 20)[b]			
Continuous	1.57	1.54, 1.61	<0.001
Residential environment composite score quintile (model 21)[b,c]			
1	1.00	Referent	Referent
2	1.18	1.13, 1.24	<0.001
3	1.91	1.82, 2.01	<0.001
4	2.28	2.16, 2.41	<0.001
5	2.59	2.43, 2.77	<0.001

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio.

[a] Adjusted for zip-code level tract population, frequency of HbA1c testing, and average time interval between HbA1c testing.

[b] Adjusted for zip-code level tract population, frequency of HbA1c testing, average time interval between HbA1c testing, and individual-level covariates.

[c] The first quintile represents the least advantaged residential environment; the fifth quintile represents the most advantaged residential environment.

Residential mobility

Web Figure 1 shows residential mobility and change in residential environment composite score from study periods time 1- (2007–2009) to time 2 (2010–2013). After the baseline period, 91,509 individuals stayed in their original zip code of residence. Overall, 2,312 individuals moved to and stayed in a residential area with a similar residential environment composite score (change in residential composite score = 0), 385 individuals moved to and stayed in a less advantaged residential area (change in composite score <0), and 420 individuals moved to and stayed in a more advantaged residential area (change in composite score >0). Web Figure 1 shows a negative relationship between mean HbA1c values and change in residential environment composite score (0.08% absolute decrease in HbA1c values per each 1-unit

Table 4. Time to Achieve Glycemic Control and Time to Failure to Maintain Glycemic Control by Residential Environment Composite Score Quintiles for Individuals Who Stayed in Their Residence, New York City, 2007–2009

HbA1c Level and Quintile of Residential Environment Composite Score Category	No.	Median time[a]	95% CI	HR	95% CI	P Value
Time to Achieve Glycemic Control						
HbA1c ≥7%[b,c]	103,479					
1	27,193	11.5	11.4, 11.7	1.00	Referent	Referent
2	29,031	11.3	11.2, 11.5	1.02	1.01, 1.03	<0.001
3	23,887	10.8	10.6, 11.0	1.09	1.08, 1.11	<0.001
4	14,868	10.6	10.4, 10.8	1.12	1.10, 1.14	<0.001
5	8,500	9.9	9.6, 10.1	1.14	1.12, 1.16	<0.001
Time to Failure to Maintain Glycemic Control						
HbA1c <7%[b,c]	79,277					
1	16,629	9.7	9.6, 9.9	1.00	Referent	Referent
2	19,681	10.1	9.9, 10.2	0.99	0.97, 0.99	<0.001
3	20,439	10.7	10.6, 10.9	0.91	0.90, 0.93	<0.001
4	13,933	11.1	10.9, 11.2	0.88	0.87, 0.90	<0.001
5	8,595	10.9	10.7, 11.1	0.87	0.85, 0.89	<0.001

Abbreviations: CI, confidence interval; HbA1c, hemoglobin A1c; HR, hazard ratio.
[a] Median time to event in months.
[b] First HbA1c test of 2007.
[c] The first quintile represents the least advantaged residential environment; the fifth quintile represents the most advantaged residential environment.

increase in residential environment composite score; $P < 0.001$). From the baseline condition of no change in score, mean HbA1c decreased by 0.16% per each 1-unit positive change in score (score >0; $P < 0.001$). This implies that change in residence to an area with a higher residential environment score is significantly associated with a 0.40% decrease in HbA1c values (95% CI: 0.22, 0.55). Conversely, compared with the baseline condition of no change in residential environment score, mean HbA1c increased by 0.11% per 1-unit decrease in score (score <0; $P < 0.001$). These results suggest that change in residence to an area with a poorer residential environment score is significantly associated with a 0.33% increase in HbA1c values (95% CI: 0.24, 0.44).

As a sensitivity analysis, we examined a less stringent HbA1c goal for glycemic control as defined by HbA1c less than 8%. Overall, the sensitivity analysis mirrored the original findings, in which some higher overall magnitudes of the associations were found (Web Tables 3 and 4).

DISCUSSION

The present study identified several residential-level socioeconomic, food, and built environment factors that were associated with glycemic control (HbA1c <7.0% and <8.0%) after adjustment for other residential environment and individual-level

Table 5. Mean Level of Hemoglobin A1c by Residential Environment Composite Score Quintiles for Individuals Who Stayed in Their Neighborhoods, New York City, 2007–2013

Residential Environment Composite Score Quintile[a]	No.	Mean HbA1c	95% CI	Difference in Mean HbA1c	P Value	Mean HbA1c Slope Overtime	P Value
1	22,832	7.67	7.65, 7.68	Referent	Referent	0.13	<0.001
2	24,571	7.48	7.46, 7.51	−0.18	<0.001	0.09	<0.001
3	21,321	7.37	7.34, 7.39	−0.30	<0.001	0.01	0.36
4	14,297	7.32	7.29, 7.34	−0.35	<0.001	0.004	0.86
5	8,488	7.23	7.21, 7.25	−0.44	<0.001	−0.01	0.46

Abbreviations: CI, confidence interval; HbA1c, hemoglobin A1c.
[a] The first quintile represents the least advantaged residential environment; the fifth quintile represents the most advantaged residential environment.

covariates. These findings suggest that residential characteristics such as more advantaged socioeconomic conditions, greater ratio of healthy and neutral food outlets compared with unhealthy food outlets, and residential walkability were positively associated with glycemic control. Conversely, less advantaged socioeconomic conditions, homicide crime, and a greater ratio of unhealthy food outlets compared with healthy and neutral food outlets were negatively associated with glycemic control.

We found that individuals who lived continuously in more advantaged residential areas with high-quality environmental resources had persistently lower mean HbA1c values and better diabetes control compared with the individuals who lived continuously in less advantaged residential areas with low-quality environment resources. Moving from less advantaged to more advantaged residential areas was related to better diabetes control as measured by lower HbA1c levels, whereas moving from more advantaged to less advantaged residential areas was related to poorer diabetes control and higher HbA1c levels during a 4-year study period (time 2). The change in HbA1c in the present study compares favorably to monotherapy with several approved pharmacologic anti-glycemic agents to treat type 2 diabetes (36, 37).

Relatively little is known about the environmental determinants of diabetes. Several cross-sectional studies have found relationship between diabetes prevalence and residential food (8), and social (38, 39) environment resources. Only a few longitudinal studies have shown direct associations between residential environments and diabetes prevalence or incidence. Poor housing (40) and living in socioeconomically less advantaged residential areas (41, 42) have been reported to be positively associated with diabetes onset, even among those with higher individual income and socioeconomic status. To our knowledge, 2 studies found that longitudinal exposure to residential environments with greater resources for physical activity and healthy foods was associated with lower incidence of type 2 diabetes (43, 44). One randomized social experiment study showed that changing residential environments (from high to low poverty) led to a reduced prevalence of obesity and type 2 diabetes (45). The group with a randomly assigned opportunity to move to a residential area with a lower poverty rate had 4.3% lower prevalence of diabetes compared with the control group. Additionally, 2 recent studies found a negative association between walkability and type 2 diabetes that were adjusted for neighborhood deprivation (46), and area income and ethnicity (47). A recent cross-sectional study has shown a positive relationship of neighborhood characteristic such as aesthetics, social support and access to healthy food, and self-care behaviors with glycemic control among individuals with diabetes (48). However, that study did not use direct measurements of residential environment; and instead evaluated the participant's perception of their neighborhood, and used self-reported scales and indices to measure neighborhood characteristics. To date, we are aware of no other studies that have directly examined the environmental determinants of diabetes control.

The present study has several limitations. First, residential self-selection may bias the associations reported, in which individuals with certain behaviors select to live in certain residential areas. Because the Registry has limited individual-level variables, we were not able to adjust for any other important individual-level variables related to residential selection beside age and sex, so unobserved individual characteristics may have influenced our results. Second, zip codes were used as the spatial scale for this analysis, which is an administrative unit that creates artificial boundaries that may not be optimal. Thus, the influences of residential resources on diabetes control may not be fully apparent using this analytical unit. Third, there may be potential sources of error and misclassification in the measures of food environment. Data from Dun & Bradstreet are used mainly for marketing purposes, so coverage may be less complete in areas that are less attractive to marketers. We controlled for residential socioeconomic composition, which may be an important correlate of measurement error in the Dun & Bradstreet data (16). Another issue is the possibility of misclassification of food outlets into the BMI-healthy, BMI-unhealthy, and BMI-neutral categories. Within-category heterogeneity in food selection may bias food environment coefficients toward zero or create interactions between residential composition and food environment characteristics (16). Although the analyses controlled for variables that might influence the level of within-category measurement error such as residential social composition and land-use mix, measurement error remains a possibility. Another limitation is the temporal mismatch between the time periods of the study (2007–2013), food environment measures and land use data (2005), population census measures (2000), and crime data (2006). Because residential demographic and built environment characteristics typically change slowly, these discrepancies should not affect the results significantly. Although we only looked at the residential areas for the present analysis, it is also possible that the working environments of individuals may affect the observed associations in the present study. In addition, we did not adjust for any time-varying covariates which could affect the analysis. Finally, as our study was based on a multi-racial and ethnic urban population, these results may not be generalizable to rural and more racially and ethnically homogenous settings.

A primary strength of the present study is the longitudinal measurement of residential environment and glycemic control status over a 7-year period in a large, multi-racial, multi-ethnic sample. We examined multiple measures within each socioeconomic, food, and built environmental feature directly and concurrently, rather than using 1 residential characteristic as a proxy for many interrelated features, which has been the case in most of the current research to date. This approach may be less susceptible to possible problems of endogeneity or reverse causation (49), in which the compositional characteristics of residential areas are determined by the individual characteristics of the residents (50). The examination of mutual and relative synergistic influence of several residential environment features is another key strength. Most studies have treated physical and social domains of residential areas as independent, but these features are interrelated and may have a combined influence on health (2). Future research is needed to understand the mutual implication of different residential environments. Use of comprehensive measures to characterize the food environment into BMI-healthy, BMI-unhealthy and BMI-neutral categories is a third strength. Although this method limits our ability to measure the association between specific food outlets and glycemic control, it provides a more accurate and complete account of food choices available to urban residents (14, 16). When only 1 food environment type is studied, the results are difficult to interpret, as residential areas with greater access to unhealthy food options may also have greater access to healthy food options (14).

In conclusion, the present analysis found an association between socioeconomic, food and built environments, and glycemic control. These results are consistent with the hypothesis that residential areas with greater resources to support healthy food, residential walkability and high socioeconomic environments are positively associated with glycemic control in persons with diabetes. Further research is needed to increase the confidence of the associations observed in the present study, especially by adjusting for time-varying individual- and residential-level environmental resources, as such findings have important implications for urban policy and population health improvement efforts. Research on other environmental exposures and factors, such as those near work and health care access environment attributes, may also be appropriate.

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