

HEALTH CARE REFORM

Neighborhood Resources for Physical Activity and Healthy Foods and Incidence of Type 2 Diabetes Mellitus

The Multi-Ethnic Study of Atherosclerosis

Amy H. Auchincloss, PhD, MPH; Ana V. Diez Roux, MD, PhD; Mahasin S. Mujahid, PhD, MS; Mingwu Shen, MS; Alain G. Bertoni, MD, MPH; Mercedes R. Carnethon, PhD

Background: Despite increasing interest in the extent to which features of residential environments contribute to incidence of type 2 diabetes mellitus, no multisite prospective studies have investigated this question. We hypothesized that neighborhood resources supporting physical activity and healthy diets are associated with a lower incidence of type 2 diabetes.

Methods: Person-level data came from 3 sites of the Multi-Ethnic Study of Atherosclerosis, a population-based, prospective study of adults aged 45 to 84 years at baseline. Neighborhood data were derived from a population-based residential survey. Type 2 diabetes was defined as a fasting glucose level of 126 mg/dL or higher (≥ 7 mmol/L) or taking insulin or oral hypoglycemic agents. We estimated the hazard ratio of type 2 diabetes incidence associated with neighborhood (US Census tract) resources.

Results: Among 2285 participants, 233 new type 2 diabetes cases occurred during a median of 5 follow-up years.

Better neighborhood resources, determined by a combined score for physical activity and healthy foods, were associated with a 38% lower incidence of type 2 diabetes (hazard ratio corresponding to a difference between the 90th and 10th percentiles for resource distribution, 0.62; 95% confidence interval, 0.43-0.88 adjusted for age, sex, family history of diabetes, race/ethnicity, income, assets, educational level, alcohol use, and smoking status). The association remained statistically significant after further adjustment for individual dietary factors, physical activity level, and body mass index.

Conclusion: Better neighborhood resources were associated with lower incidence of type 2 diabetes, which suggests that improving environmental features may be a viable population-level strategy for addressing this disease.

Arch Intern Med. 2009;169(18):1698-1704

Author Affiliations:

Department of Epidemiology and Biostatistics, School of Public Health, Drexel University, Philadelphia, Pennsylvania (Dr Auchincloss); Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor (Dr Diez Roux and Ms Shen); Department of Epidemiology, School of Public Health, University of California, Berkeley (Dr Mujahid); Division of Public Health Sciences, Wake Forest University School of Medicine, Winston-Salem, North Carolina (Dr Bertoni); and Department of Preventive Medicine, Feinberg School of Medicine, Northwestern University, Chicago, Illinois (Dr Carnethon).

THE WORLDWIDE EPIDEMIC OF type 2 diabetes mellitus is largely driven by the combined rise in obesity, intake of energy-dense or nutrient-poor foods, and physical inactivity. Individual-based approaches to reverse this epidemic, including surgical treatment,

For editorial comment see page 1653

medication, and behavior modification, have yielded mixed results.^{1,2} Meanwhile, community trends in diabetes incidence continue to worsen.³ It has been argued that large-scale behavioral change is necessary to forestall the epidemic, but behavioral change is often difficult and is not sustainable in unsupportive environments. There is growing recognition that

population-level environmental interventions have the potential to alter sociocultural norms in health behaviors.⁴ The presence of resources that support physical activity and a healthy diet are environmental features that could affect the development of type 2 diabetes.

Cross-sectional evidence exists that neighborhood resources are associated with precursors to type 2 diabetes, as measured by body mass index (BMI)^{5,6} (calculated as weight in kilograms divided by height in meters squared) and insulin resistance.⁷⁻⁹ Yet, to our knowledge, only 2 longitudinal studies have examined whether neighborhood characteristics are associated with type 2 diabetes, and both included limited measures of the relevant environmental features and were limited to small or restricted single-site samples.^{10,11} No longitudinal study, to our knowledge, has examined whether

Table 1. Community Survey Questionnaire Items for Neighborhood Scales

Neighborhood Scale	Questionnaire Items
Suitability of the environment for physical activity	<ol style="list-style-type: none"> 1. My neighborhood offers many opportunities to be physically active. 2. Local sports clubs and other facilities in my neighborhood offer many opportunities to get exercise. 3. It is pleasant to walk in my neighborhood. 4. In my neighborhood, it is easy to walk places. 5. I often see other people walking in my neighborhood. 6. I often see other people exercise (for example, jog, bicycle, or play sports) in my neighborhood.
Availability of healthy foods	<ol style="list-style-type: none"> 1. A large selection of fresh fruits and vegetables is available in my neighborhood. 2. The fresh fruits and vegetables in my neighborhood are of high quality. 3. A large selection of low-fat products is available in my neighborhood.

neighborhood resources, specifically for physical activity and healthy foods, are associated with incident type 2 diabetes in a large, multisite population sample. The identification of an effect of neighborhood features on the development of type 2 diabetes would support prevention efforts that target environmental features.

We examined whether neighborhood resources that support being physically active and having a healthy diet are associated with incidence of type 2 diabetes during 5 years of follow-up in a large and diverse population-based sample. We hypothesized that the incidence of type 2 diabetes was inversely associated with these 2 neighborhood features.

METHODS

PERSON-LEVEL DATA

Person-level data used in these analyses came from the Multi-Ethnic Study of Atherosclerosis (MESA). The MESA recruited persons aged 45 to 84 years from 6 sites using a variety of population-based approaches, including commercial lists of area residents and random-digit dialing.¹² Only persons without clinical cardiovascular disease at baseline were eligible. For this analysis, we included participants enrolled at 3 sites for which neighborhood-level data were obtained: Baltimore (city) and Baltimore County, Maryland; Forsyth County, North Carolina; and New York City/Bronx, New York. Data were used from the baseline examination (collected from 2000 to 2002) and 3 follow-up examinations that occurred approximately 1.6, 3.1, and 4.8 years later. Retention rates were high (94%, 89%, and 86%, respectively, for the 3 follow-up visits). All participants provided written, informed consent, and the study was approved by the institutional review boards at all participating institutions.

TYPE 2 DIABETES

Glucose levels were ascertained from blood samples obtained after a 12-hour fast and assayed by rate reflectance spectrophotometry using the thin-film adaptation of the glucose oxidase method on the Vitros analyzer (Johnson & Johnson Clinical Diagnostics, Inc, Rochester, New York). Type 2 diabetes was defined using the American Diabetes Association 2003 criteria¹³: fasting glucose level of 126 mg/dL or higher (to convert to millimoles per liter, multiply by 0.0555) or taking insulin or oral hypoglycemic agents. Information on the use of insulin or oral hypoglycemic agents was obtained by visual inspection of medications or if the participant twice self-reported use on study questionnaires. Incident diabetes

was determined in participants who did not have type 2 diabetes at baseline.

MEASUREMENT OF COVARIATES

Covariates measured at baseline were age, sex, self-classified race/ethnicity, per capita household income, household assets (owns home, investments, or property other than primary home), educational level, cigarette smoking status, high weekly alcohol consumption (upper 10th percentile among study participants), and family history of diabetes (positive if the participant had at least 1 diabetic blood-relative parent in addition to at least 1 diabetic blood-relative sibling¹⁴).

Body mass index was measured at all examinations. Physical activity was assessed from metabolic equivalent task-hours per day for walking and moderate- and vigorous-intensity sports and conditioning activities from a physical activity questionnaire at baseline and at 2 follow-up examinations.^{12,15} Dietary measurements were compiled from a food frequency questionnaire administered only at baseline and were summarized using an index (derived from principal components analysis of these data¹⁶) that quantified consumption of fiber (whole grain bread, rice, and pasta), fruit, seeds/nuts, green leafy vegetables, and low-fat milk. Components of this index have been associated with less insulin resistance (a precursor to type 2 diabetes) either because of their intrinsic health-promoting properties or because they are proxies for a "healthy" diet.^{17,18}

NEIGHBORHOOD-LEVEL DATA

Measures of neighborhood resources were obtained from an independent sample: the Community Survey,¹⁹ a population-based random-digit dialing telephone survey conducted as part of the MESA¹² ancillary Neighborhood Study. We used a sample that was independent but co-located with the original study's sites and participants to avoid spurious associations that can result when neighborhood information and behaviors are self-reported by the same participants.^{20,21} Community Survey data were collected in 2004 (the midpoint of the MESA follow-up period) from 5988 persons residing in the city of Baltimore and Baltimore County, Forsyth County, and New York City/Bronx. Two scales were used in this study: suitability of the environment for physical activity and availability of healthy foods (**Table 1**). Residents were asked, for example, if it was "pleasant" and "easy" to walk in their neighborhood and if there were nearby exercise facilities. They were asked if a large, high-quality selection of fruits, vegetables, and low-fat foods was available in their neighborhood. The interviewer explicitly defined neighborhood as "the area within about a 20-minute walk or about a mile from your home" (ie, 1.6 km). Item responses from the residential survey were weighted to account for the differential probabilities of selection into the sample (based on the number

of telephones in the household) and the number of adults in the household and were adjusted for age and sex of the respondents because of the influence of those characteristics on the neighborhood ratings (eg, women may be more likely to purchase food for the household and would be more knowledgeable about food availability and quality). Survey items had a possible score range of 1 to 5; higher scores indicated better resources. Both scale internal consistency and test-retest reliability were acceptably high (Cronbach α , ≥ 0.73 ; 2-week test-retest reliability, ≥ 0.60). Within a tract there was reasonable participant agreement (0.43 and 0.28 intraneighborhood correlation coefficient for physical activity environment and healthy foods environment, respectively), and, thus, tracts were used as a proxy for neighborhoods. Additional details on the survey are reported elsewhere.¹⁹ Responses within a tract were aggregated using empirical Bayes estimation,²² and tract-level characteristics were subsequently linked to MESA participants' US Census tract; MESA participants whose data were used in this study resided in 416 tracts with a median of 6 participants per tract.

STUDY PARTICIPANTS

Of 3265 participants enrolled at baseline in the parent study at 3 study sites, 2963 agreed to participate (90.8%),¹² and 2606 (79.8%) did not have type 2 diabetes at baseline. A total of 321 persons without type 2 diabetes at baseline (12.3%) were excluded for the following reasons: address errors (n=77), missing information on diabetes (n=13), neighborhood-level exposures (n=91), and key covariates (n=140). Therefore, 2285 of 2606 participants (87.7%) were included in the main analyses. An additional 267 persons with missing dietary information (10.2%) were excluded from analyses that used the diet index. Among the 2606 eligible participants, demographic characteristics were roughly similar for excluded and included persons.

STATISTICAL ANALYSES

We first classified neighborhood resources into tertiles and used the tertiles to examine the distribution of individual-level variables for persons who did and did not develop type 2 diabetes (**Table 2**) as well as the age- and sex-adjusted type 2 diabetes incidence rates^{23,24} (**Table 3**). Because events occurred during the interval between examination dates (interval-censoring), regression models used parametric accelerated failure time estimation to derive adjusted hazard ratios (HRs) for incident diabetes. The Weibull distribution was selected as the best-fitting accelerated failure time function after comparing model likelihood ratios fit for Weibull, exponential, and gamma distributions. To examine which adjustment variables had a strong influence on type 2 diabetes risk, we adjusted the model in stages (**Table 4**). Models were adjusted for age, sex, family history of diabetes, per capita household income, household assets, educational level, race/ethnicity, alcohol consumption, and cigarette smoking status. Independent variables were not highly colinear, which permitted examination of their independent effects (Pearson correlation between neighborhood resources and individual-level income, $r=0.20$). We examined the potential mediating effect of individual-level physical activity, dietary factors, and BMI on the neighborhood association with type 2 diabetes incidence, and we compared HRs before and after adjustment for these variables. We examined the sensitivity of our results to more sophisticated approaches in the following ways: (1) using available time-varying covariates (examinations 2-4) and (2) allowing for within-neighborhood correlations in the response (interval-censored accelerated failure time models cannot easily be modified; therefore, proportional hazards regression was used for those analyses).

We also assessed the contribution of baseline glucose impairment (impaired fasting glucose [IFG] and fasting glucose level, 100-125 mg/dL) to incident type 2 diabetes by examining whether results changed before and after including baseline IFG in the regression model. This will be reported as sensitivity analyses because the extent to which baseline IFG should be statistically controlled in our study is debatable, given that development of IFG may be in the causal pathway linking prior neighborhood conditions to incident diabetes.²⁵

There was no evidence of a threshold or nonlinear relationship between adjusted neighborhood conditions and type 2 diabetes. Therefore, continuous neighborhood variables were used in regression analysis. The 2 neighborhood characteristics (physical activity and healthy food resources) were investigated separately and combined into a summary score (the mean of the 2 scores). The correlation between the 2 neighborhood scores was high (Pearson $r > 0.71$), thereby prohibiting examination of their independent effects. To compare associations for neighborhood variables that have different units, estimates shown correspond to differences between the 90th and 10th percentiles of the neighborhood variable (translating to differences of 0.75 for the physical activity scale [range, 2.76-4.63], 0.88 for the healthy foods scale [range, 2.55-4.53], and 0.71 for the summary scale [range, 2.70-4.56]). Inference remained the same when an alternate unit, the interquartile range, was used.

Based on previous literature, we tested whether the following baseline variables modified the association between neighborhood features and incident type 2 diabetes: age, sex, income, household car ownership, and study site. We also examined whether neighborhood effects on type 2 diabetes incidence differed by obesity at baseline, mobility patterns (exercised or shopped for food in the neighborhood [≤ 1 mile] and car ownership, which may suggest the degree to which participants are constrained to their neighborhood), and duration of neighborhood exposure (years of residence in the neighborhood and whether participants moved from their baseline address). We assessed statistically significant departures from assumptions of multiplicative and additive joint effects (relative excess risks owing to interaction²⁶).

RESULTS

During a median of 5 years of follow-up, 233 of 2285 participants (9460 person-years) were diagnosed as having type 2 diabetes (10.2%) (Table 2). The mean neighborhood score for physical activity was slightly higher than for healthy foods (3.68 vs 3.36, respectively, on a scale of 1-5). The neighborhood score was less favorable among persons with type 2 diabetes at follow-up (combined score of 3.45 among new type 2 diabetes cases vs 3.53 for others; $t=3.67$; $P < .001$), and persons living in worse environments generally had less favorable risk-factor profiles, income and assets, smoking status, dietary factors, physical activity level, BMI, and baseline prevalence of impaired glucose. There was a graded reduction in age- and sex-adjusted type 2 diabetes incidence rates with better neighborhood environments (Table 3). For example, per 1000 person-years, type 2 diabetes incidence was 28.7, 27.0, and 16.3 among persons living in the worst, intermediate, and best neighborhoods for being physically active, respectively.

In adjusted analyses, established risk factors (covariates) generally showed the expected associations with type 2 diabetes incidence, although confidence intervals (CIs) included the null for all covariates except sex

Table 2. Type 2 Diabetes Incidence at Follow-up and Neighborhood Resources for Physical Activity and Healthy Foods^a

	Total Sample	Type 2 Diabetes ^b at Follow-Up		Neighborhood Physical Activity and Healthy Foods, ^c Summary Score		
		No	Yes	Worst	Intermediate	Best
No. of participants	2285	2052	233	760	764	761
Demographic Characteristics						
Age, y, mean (SD)	62.1 (10.0)	62.1 (10.0)	62.0 (10.1)	62.3 (9.8)	62.3 (9.7)	61.7 (10.5)
Men	45	44	49	45	44	45
Race/ethnicity ^d						
White	44	46	34	27	46	60
African American	40	39	48	62	36	22
Hispanic	16	15	18	11	18	18
Family history of diabetes	7	6	13	9	7	5
Socioeconomic Status						
Per capita household income, per \$10 000, mean (SD)	2.80 (1.91)	2.83 (1.93)	2.52 (1.74)	2.36 (1.64)	2.79 (1.80)	3.24 (2.16)
Low assets ^e	19	18	24	21	19	16
Education, y, mean (SD)	13.6 (3.4)	13.7 (3.4)	13.1 (3.7)	13.1 (3.4)	13.5 (3.5)	14.3 (3.3)
Other Risk Factors/Health Behaviors						
Smoking status						
Never	46	46	42	43	48	46
Former	41	40	46	41	39	42
Current	13	14	12	16	13	12
High alcohol use	13	13	11	10	12	16
Favorable diet index, ^f mean (SD)	0.17 (0.98)	0.19 (0.99)	0.01 (0.90)	0.07 (0.96)	0.19 (0.94)	0.26 (1.03)
Physical activity level, h/d, mean (SD)	5.8 (7.3)	5.9 (7.4)	5.1 (6.1)	5.5 (8.3)	5.6 (6.4)	6.2 (7.0)
BMI, mean (SD)	28.7 (5.4)	28.4 (5.2)	31.6 (6.2)	29.4 (5.6)	29.0 (5.5)	27.8 (5.0)
Obese at first examination, BMI ≥30	34	31	53	40	34	27
Outcome Information						
Diabetes at any follow-up examination ^b	10	90	10	13	11	7
Glucose level impaired at baseline ^b	14	9	54	16	15	10
Neighborhood Resources^c						
Physical activity, mean (SD)	3.68 (0.31)	3.69 (0.31)	3.62 (0.29)	3.42 (0.19)	3.64 (0.13)	3.99 (0.27)
Healthy foods, mean (SD)	3.36 (0.36)	3.37 (0.37)	3.29 (0.34)	3.02 (0.18)	3.32 (0.14)	3.75 (0.27)
Summary score, mean (SD)	3.52 (0.31)	3.53 (0.31)	3.45 (0.29)	3.22 (0.13)	3.48 (0.07)	3.87 (0.24)

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

SI conversion factor: To convert glucose to millimoles per liter, multiply by 0.0555.

^aData are given as the percentage of participants unless otherwise indicated.

^bType 2 diabetes was defined according to American Diabetes Association 2003 criteria: fasting glucose level of 126 mg/dL or higher (to convert glucose to millimoles per liter, multiply by 0.0555) or taking insulin or oral hypoglycemic agents.

^cNeighborhood measures, collected from a population-based residential survey (the Community Survey; see the "Methods" section) were aggregated to census tracts using empirical Bayes estimation. Item responses had a possible range of 1 to 5; higher scores indicate better resources. Both neighborhood characteristics (physical activity and healthy food resources) were combined into a summary score and then classified into tertiles (worst, 2.7 to <3.37; intermediate, 3.37 to <3.61; best, 3.61 to 4.56).

^dThe Multi-Ethnic Study of Atherosclerosis enrolled ethnic Chinese, white, African-American, and Hispanic participants at 6 field sites. These analyses were restricted to 3 sites (New York City/Bronx, city of Baltimore, and Baltimore and Forsyth Counties) that did not enroll ethnic Chinese participants.

^eDefined as meeting all the following conditions: does not own home outright, does not have investments, and does not have additional property other than primary home.

^fA higher score indicates a better diet.

(men had a higher incidence), family history of diabetes, and BMI (results not shown). Higher levels of neighborhood resources that support being physically active and having a healthy diet were associated with lower type 2 diabetes incidence and, in general, patterns were very similar for each score separately as well as for the summary score (Table 4). After adjustment for age, sex, and family history of diabetes, incidence of type 2 diabetes corresponding to a difference between the 90th and 10th percentiles was 43% lower for physical activity resources (HR, 0.57; 95% CI, 0.41-0.81) and 46% lower for healthy food resources (0.54; 0.38-0.77). Additional adjustment for socioeconomic status (family income and

assets) and race/ethnicity attenuated the magnitude of the associations, but they remained statistically significant. Adjustment for high alcohol use and cigarette smoking had no additional effect on estimates (adjusted HR corresponding to a difference between the 90th and 10th percentiles in combined neighborhood resources was 0.62; 95% CI, 0.43-0.88). In total, the neighborhood association was further reduced by approximately 0% to 19% after the addition of proposed mediating variables (individual physical activity level, diet, and BMI); the largest reduction was in neighborhood physical activity resources after adjustment for BMI (ie, comparing model 4 with an HR of 0.64 to model 6 with an HR of 0.71²⁷)

Table 3. Incidence of Type 2 Diabetes^a by Tertiles of Neighborhood Scores^b

Neighborhood Resources	Incidence per 1000 Person-Years (95% Confidence Interval)		
	Tertile 1, Worst	Tertile 2, Intermediate	Tertile 3, Best
Physical activity	28.7 (23.1-35.6)	27.0 (21.8-33.4)	16.3 (12.5-21.4)
Healthy foods	31.4 (25.7-38.4)	26.8 (21.6-33.2)	15.5 (11.8-20.4)

^aType 2 diabetes was defined according to American Diabetes Association 2003 criteria: fasting glucose level of 126 mg/dL or higher (to convert glucose to millimoles per liter, multiply by 0.0555) or taking insulin or oral hypoglycemic agents.

^bFor this table, Poisson regression was used to estimate age- and sex-adjusted incidence rates (sum of events/person-years) according to neighborhood exposures; person-years were approximated by using midpoints between clinic visits. Neighborhood measures, collected from a population-based residential survey (the Community Survey; see the "Methods" section), were aggregated to census tracts using empirical Bayes estimation. Item responses had a possible range of 1 to 5; higher scores indicate better resources.

Table 4. Adjusted HRs for Type 2 Diabetes Incidence Corresponding to a Difference Between the 90th and 10th Percentiles in Neighborhood Resources

Model No. + Progressive Adjustment	Neighborhood Resources					
	Physical Activity		Healthy Foods		Physical Activity and Healthy Food Resources, Summary Score	
	HR (95% CI)	P Value	HR (95% CI)	P Value	HR (95% CI)	P Value
1. Age, ^a sex, family history of diabetes	0.57 (0.41-0.81)	.001	0.54 (0.38-0.77)	<.001	0.54 (0.39-0.76)	<.001
2. Model 1 + income, ^a assets, and educational level	0.61 (0.43-0.86)	.005	0.58 (0.41-0.82)	.002	0.58 (0.41-0.81)	.001
3. Model 2 + race/ethnicity	0.65 (0.46-0.93)	.02	0.63 (0.44-0.91)	.01	0.62 (0.44-0.89)	.008
4. Model 3 + high alcohol intake and cigarette smoking status	0.64 (0.45-0.92)	.02	0.63 (0.44-0.91)	.01	0.62 (0.43-0.88)	.007
5. Model 4 + physical activity level ^b and diet index ^c	0.65 (0.44-0.97)	.03	0.58 (0.39-0.86)	.007	0.59 (0.40-0.87)	.008
6. Model 5 + BMI	0.71 (0.48-1.05)	.09	0.63 (0.42-0.93)	.02	0.64 (0.44-0.95)	.03

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CI, confidence interval; HR, hazard ratio.

^aAge and income had nonlinear adjusted relationships with incident type 2 diabetes; therefore, regression models incorporated a quadratic term for age and piecewise linear splines for income.

^bIndividual physical activity level was assessed as metabolic equivalent task-hours per day for walking and moderate and vigorous intensity sports and conditioning activities as reported on a physical activity questionnaire.

^cIndividual-level dietary profiles were collected only at baseline. An individual-level diet index was compiled from baseline dietary profiles (see the "Methods" section).

(Table 4). Reductions were similar when time-varying covariates were used (data not shown).

Results were similar after including baseline IFG in the regression model (adjusting for age, sex, family history of diabetes, socioeconomic status, race/ethnicity, smoking status, and alcohol use: HR, 0.62; 95% CI, 0.43-0.87; additional adjustment for physical activity level, dietary factors, and BMI [not shown in tables]: 0.60; 0.41-0.88). In general, sensitivity analyses yielded similar results when models were fit with time-varying covariates and when robust sandwich estimators were used to allow for within-neighborhood correlations in the response.

Neighborhood resources had a stronger inverse association with type 2 diabetes incidence for persons younger than 60 years at baseline (approximate median age); however, a protective relationship was suggested for both groups (baseline age <60 years: HR, 0.38; 95% CI, 0.20-0.70 vs baseline age ≥60 years: 0.78; 0.48-1.25; *P* for multiplicative interaction=.02; *P* for additive interaction=.57; adjusted for sex, family history of diabetes, socioeconomic status, race/ethnicity, smoking status, and alcohol use). There was no significant heterogeneity by sex, obesity at baseline, study site, and mobility patterns (car ownership, distance traveled from home for food shopping, distance traveled from

home for exercise; data not shown; *P* for multiplicative and additive interactions ≥.09). There was no significant heterogeneity by duration of years lived in a neighborhood or whether the participant relocated during the study follow-up period (interaction *P*>.20). During the study period, 17% of participants moved out of their baseline neighborhood but relocated to neighborhoods that shared similar characteristics (Pearson correlation between pre- and postmove neighborhood scores, *r*=0.60).

COMMENT

In this cohort study, the features of residential environment that support physical activity and healthy diets were associated with lower incidence of type 2 diabetes during 5 years of follow-up. Associations between type 2 diabetes incidence and residential environment persisted after adjustment for individual-level variables, including age, sex, family history of diabetes, socioeconomic characteristics, smoking status, alcohol intake, physical activity level, and dietary factors. They were slightly reduced after additional adjustment for baseline BMI.

Considering the distal relationship between residential conditions and their biological manifestations, it is noteworthy that we found an effect of such large magnitude: at least 36% lower diabetes incidence during 5 years' follow-up corresponding to a difference between the 90th and 10th percentiles in physical activity and food environments (or a 20% lower diabetes incidence when the neighborhood unit represented the interquartile range). The strength of the association was considerable and equivalent to a reduction in type 2 diabetes incidence associated with a BMI of 5 values lower in this sample. Associations of neighborhood resources with incident diabetes even persisted after controlling for baseline elevated glucose levels.

Our analyses only weakly suggested that individual-level dietary factors, physical activity level, and BMI were intermediaries in the association between neighborhood resources and diabetes incidence. This may reflect measurement error for individual health behaviors, which are notoriously difficult to measure. In addition, health behaviors were not measured at each follow-up visit (eg, dietary factors were measured only at baseline). Furthermore, teasing apart specific mediating pathways is difficult because of the distal relationships and time lags involved, as well as problems inherent in separating direct and indirect effects in regression analyses.^{28,29} Future analyses are being planned that will improve investigation of these intermediaries by examining direct associations between neighborhood resources and these hypothesized mediators (work that was outside the scope of this study) and by using forthcoming data collected over a longer follow-up period.

One of the strengths of the neighborhood data we used is that we assessed multiple dimensions of specific aspects of the physical environment that plausibly have direct relevance to the development of diabetes. The extent to which availability of resources relates to resource utilization remains a complex question that this study did not answer. However, our data ascertained neighborhood resource access, quality, quantity, and diversity, factors that impact population-level resource utilization.³⁰⁻³²

This study followed up participants for 5 years. However, type 2 diabetes develops slowly over a long period, making long-term chronic exposures most relevant. Most participants had resided in their neighborhoods for a long time (median, 17 years at baseline); therefore, to the extent that neighborhood environments remain stable over time, participants may have had long-term exposure to resources in their neighborhood. Although some participants moved out of their baseline neighborhood during the study, they tended to relocate to neighborhoods that shared similar characteristics, and there was high correlation between pre- and postmove neighborhood scores. Neighborhood effects on the incidence of type 2 diabetes were similar between movers and nonmovers.

Among the strengths of this study are that we assessed incident diabetes during multiple follow-up visits among a large, multisite, population-based, multiethnic sample. Very few studies have examined the effects of neighborhood resources on incident disease. Nevertheless, this study is subject to well-known limitations of using observational data for causal inference.³³ For ex-

ample, there is the possibility that residual confounding and self-selection into neighborhoods could account for some of the observed results (eg, active individuals tend to self-select neighborhoods that are suitable for being physically active).^{34,35} We used causal diagrams³⁶ to anticipate important confounders and carefully adjusted for a number of individual-level variables. The ability of persons to self-select neighborhoods likely depends on personal characteristics (eg, income and race/ethnicity); therefore, we adjusted for these variables in multivariable regression. Replication of our results would increase confidence in our findings, and we encourage future research using a variety of study designs and methods to examine the effects of neighborhood resources on incident diabetes. Future research could evaluate changes in neighborhood environments via quasi-experiments (ie, "natural experiments") or through specifically designed randomized trials. Yet, even those study designs can be suboptimal for answering our research question because there are logistical and ethical concerns as well as limitations to generalizability.³⁷ Therefore, it is likely that multiple types of evidence, including observational data, will be needed to determine the desirability and effectiveness of policy interventions targeting neighborhood environments.

The prevalence of type 2 diabetes has increased substantially in the past 30 years. This makes it all the more urgent to identify environmental features that may mitigate risk of type 2 diabetes. Our results are consistent with the hypotheses that improving environmental features such as having nearby, pleasant, safe destinations within walking distance and improving the availability of healthy foods may halt increases in type 2 diabetes incidence. Many urban environments have developed with insufficient consideration for the ways that environments can promote or discourage healthy behaviors. Current efforts to foster health-promoting environments include designing and modifying physical environments, such as zoning residential neighborhoods to require safe sidewalks, creating parks and attractive public green spaces, and improving public transportation so that residents rely less on their cars³⁸; supporting fresh-food farmers' markets in low-income, urban neighborhoods; and assisting stores in those neighborhoods in improving their selection of healthy foods.^{39,40} There is unlikely to be a panacea for the obesity epidemic and rising epidemic of type 2 diabetes. However, altering our environments so that healthier behaviors and lifestyles can be easily chosen may be one of the key steps in arresting and reversing these epidemics.

Accepted for Publication: June 19, 2009.

Correspondence: Amy H. Auchincloss, PhD, MPH, Department of Epidemiology and Biostatistics, School of Public Health, Drexel University, Mail Stop 1033, 1505 Race St, 6th Floor, Philadelphia, PA 19102 (aha27@drexel.edu).

Author Contributions: Drs Auchincloss, Diez Roux, Mujahid, and Bertoni had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Auchincloss and Diez Roux. *Acquisition of data:*

Diez Roux and Bertoni. *Analysis and interpretation of data:* Auchincloss, Diez Roux, Mujahid, Shen, and Carnethon. *Drafting of the manuscript:* Auchincloss and Diez Roux. *Critical revision of the manuscript for important intellectual content:* Auchincloss, Diez Roux, Mujahid, Bertoni, and Carnethon. *Statistical analysis:* Auchincloss and Shen. *Obtained funding:* Diez Roux. *Administrative, technical, and material support:* Diez Roux. *Study supervision:* Diez Roux.

Financial Disclosure: None reported.

Funding/Support: This research was supported by contracts R01 HL071759 and N01-HC-95159 through N01-HC-95165 and N01-HC-95169 from the National Heart, Lung, and Blood Institute, National Institutes of Health.

Group Information: A full list of participating MESA investigators and institutions can be found at <http://www.mesa-nhlbi.org>.

Additional Contributions: We thank the other investigators, the staff, and the participants of the MESA study for their valuable contributions.

REFERENCES

- Dansinger ML, Tatsioni A, Wong JB, Chung M, Balk EM. Meta-analysis: the effect of dietary counseling for weight loss. *Ann Intern Med.* 2007;147(1):41-50.
- Simons-Morton DG, Obarzanek E, Cutler JA. Obesity research: limitations of methods, measurements, and medications. *JAMA.* 2006;295(7):826-828.
- Cowie CC, Rust KF, Ford ES, et al. Full accounting of diabetes and pre-diabetes in the U.S. population in 1988-1994 and 2005-2006. *Diabetes Care.* 2009;32(2):287-294.
- Brownson RC, Baker EA, Housemann RA, Brennan LK, Bacak SJ. Environmental and policy determinants of physical activity in the United States. *Am J Public Health.* 2001;91(12):1995-2003.
- Mujahid MS, Diez Roux AV, Shen M, et al. Relation between neighborhood environments and obesity in the Multi-Ethnic Study of Atherosclerosis. *Am J Epidemiol.* 2008;167(11):1349-1357.
- Morland K, Diez Roux AV, Wing S. Supermarkets, other food stores, and obesity: the Atherosclerosis Risk in Communities Study. *Am J Prev Med.* 2006;30(4):333-339.
- Diez Roux AV, Jacobs DR, Kiefe CI; Coronary Artery Risk Development in Young Adults (CARDIA) Study. Neighborhood characteristics and components of the insulin resistance syndrome in young adults: the Coronary Artery Risk Development in Young Adults (CARDIA) study. *Diabetes Care.* 2002;25(11):1976-1982.
- Auchincloss AH, Diez Roux AV, Brown DG, O'Meara ES, Raghunathan TE. Association of insulin resistance with distance to wealthy areas: the Multi-Ethnic Study of Atherosclerosis. *Am J Epidemiol.* 2007;165(4):389-397.
- Auchincloss AH, Diez Roux AV, Brown DG, Erdmann CA, Bertoni AG. Neighborhood resources for physical activity and healthy foods and their association with insulin resistance. *Epidemiology.* 2008;19(1):146-157.
- Cox M, Boyle PJ, Davey PG, Feng Z, Morris AD. Locality deprivation and type 2 diabetes incidence: a local test of relative inequalities. *Soc Sci Med.* 2007;65(9):1953-1964.
- Schootman M, Andresen EM, Wolinsky FD, et al. The effect of adverse housing and neighborhood conditions on the development of diabetes mellitus among middle-aged African Americans. *Am J Epidemiol.* 2007;166(4):379-387.
- Bild DE, Bluemke DA, Burke GL, et al. Multi-Ethnic Study of Atherosclerosis: objectives and design. *Am J Epidemiol.* 2002;156(9):871-881.
- Genuth S, Alberti KG, Bennett P, et al; Expert Committee on the Diagnosis and Classification of Diabetes Mellitus. Follow-up report on the diagnosis of diabetes mellitus. *Diabetes Care.* 2003;26(11):3160-3167.
- Weijnen CF, Rich SS, Meigs JB, Krolewski AS, Warram JH. Risk of diabetes in siblings of index cases with type 2 diabetes: implications for genetic studies. *Diabet Med.* 2002;19(1):41-50.
- Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc.* 2000;32(9)(suppl):S498-S504.
- Nettleton JA, Steffen LM, Mayer-Davis EJ, et al. Dietary patterns are associated with biochemical markers of inflammation and endothelial activation in the Multi-Ethnic Study of Atherosclerosis (MESA). *Am J Clin Nutr.* 2006;83(6):1369-1379.
- Pereira MA, Jacobs DR Jr, Pins JJ, et al. Effect of whole grains on insulin sensitivity in overweight hyperinsulinemic adults. *Am J Clin Nutr.* 2002;75(5):848-855.
- Liese AD, Roach AK, Sparks KC, Marquart L, D'Agostino RB Jr, Mayer-Davis EJ. Whole-grain intake and insulin sensitivity: the Insulin Resistance Atherosclerosis Study. *Am J Clin Nutr.* 2003;78(5):965-971.
- Mujahid MS, Diez Roux AV, Morenoff JD, Raghunathan T. Assessing the measurement properties of neighborhood scales: from psychometrics to ecometrics. *Am J Epidemiol.* 2007;165(8):858-867.
- Duncan GJ, Raudenbush S. Neighborhoods and adolescent development: how can we determine the links? In: Booth A, Crouter AC, eds. *Does It Take a Village? Community Effects on Children, Adolescents, and Families.* State College: Pennsylvania State University Press; 2001:105-136.
- Raudenbush SW. The quantitative assessment of neighborhood social environments. In: Kawachi I, Berkman LB, eds. *Neighborhoods and Health.* New York, NY: Oxford University Press; 2003:132-146.
- Clayton D, Kaldor J. Empirical Bayes estimates of age-standardized relative risks for use in disease mapping. *Biometrics.* 1987;43(3):671-681.
- Joffe MM, Greenland S. Standardized estimates from categorical regression models. *Stat Med.* 1995;14(19):2131-2141.
- Zhao D. Poisson regression adjustment of event rates and its macro procedure ADJ_POIS. Paper presented at: SAS Users Group 24th International Annual Conference; April 11, 1999; Miami Beach, FL.
- Glymour MM, Weuve J, Berkman LF, Kawachi I, Robins JM. When is baseline adjustment useful in analyses of change? an example with education and cognitive change. *Am J Epidemiol.* 2005;162(3):267-278.
- Li R, Chambless L. Test for additive interaction in proportional hazards models. *Ann Epidemiol.* 2007;17(3):227-236.
- Breslow NE, Day NE. Statistical methods in cancer research, volume I: the analysis of case-control studies. *IARC Sci Publ.* 1980;(32):5-338.
- Blakely T. Commentary: estimating direct and indirect effects—fallible in theory, but in the real world? *Int J Epidemiol.* 2002;31(1):166-167.
- Cole SR, Hernan MA. Fallibility in estimating direct effects. *Int J Epidemiol.* 2002;31(1):163-165.
- Giles-Corti B, Broomhall MH, Knuiam M, et al. Increasing walking: how important is distance to, attractiveness, and size of public open space? *Am J Prev Med.* 2005;28(2)(suppl 2):169-176.
- Lee C, Moudon AV. Physical activity and environment research in the health field: implications for urban and transportation planning practice and research. *J Plann Lit.* 2004;19:147-181.
- Sloane D, Nascimento L, Flynn G, et al. Assessing resource environments to target prevention interventions in community chronic disease control. *J Health Care Poor Underserved.* 2006;17(2)(suppl):146-158.
- Winship C, Morgan SL. The estimation of causal effects from observational data. *Annu Rev Sociol.* 1999;25:659-706.
- Handy S. Community design and physical activity: what do we know and what don't we know? Obesity and the Built Environment: Improving Public Health Through Community Design. National Institute of Environmental Health Sciences web site. <http://www.niehs.nih.gov/news/events/pastmtg/2004/built/information.cfm>. Accessed June 1, 2009.
- Handy S, Cao X, Mokhtarian P. Correlation or causality between the built environment and travel behavior? evidence from Northern California. *Transp Res Part D Transp Environ.* 2005;10:427-444.
- Fleischer NL, Diez Roux AV, Alazraqui M, Spinelli H. Social patterning of chronic disease risk factors in a Latin American city. *J Urban Health.* 2008;85(6):923-937.
- Subramanian SV. The relevance of multilevel statistical methods for identifying causal neighborhood effects. *Soc Sci Med.* 2004;58(10):1961-1967.
- Sustainable Communities Network. <http://www.smartgrowth.org/library/projects.asp>. Accessed August 1, 2009.
- Glanz K, Yaroch AL. Strategies for increasing fruit and vegetable intake in grocery stores and communities: policy, pricing, and environmental change. *Prev Med.* 2004;39(suppl 2):S75-S80.
- The Food Trust. <http://www.thefoodtrust.org/php/about/index.php>. Accessed August 1, 2009.