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Original Contribution

Association of Insulin Resistance with Distance to Wealthy Areas

The Multi-Ethnic Study of Atherosclerosis

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Little is known about environmental determinants of type 2 diabetes. The authors hypothesized that insulin resistance is positively related to distance to a wealthy area and to local neighborhood poverty. Data were derived from The Multi-Ethnic Study of Atherosclerosis, a study of adults aged 45–84 years in six US locales, and the 2000 US Census. The homeostasis model assessment (HOMA) index was used to measure insulin resistance. Linear regression was used to estimate associations between area characteristics and insulin resistance after adjustment for age, sex, income, education, and race/ethnicity and for the potential mediators diet, physical activity, and body mass index ($n = 4,821$). Among persons not treated for diabetes, distance to a wealthy area was associated with HOMA independent of local poverty and person-level covariates: per 4.4-km change, the relative increase in HOMA was 13% (95% confidence interval: 7%, 19%), similar to the effect of a body mass index increase of 1.7 kg/m^2 on HOMA. This association was reduced after adjustment for physical activity, diet, and body mass index (relative increase = 9%, 95% confidence interval: 3%, 15%). Local neighborhood poverty was also positively, but more weakly associated with insulin resistance, with no association after adjustment for race/ethnicity. This study shows that proximity to resources in high-income areas is related to insulin resistance.

diabetes mellitus, type 2; environment; geographic information systems; insulin resistance; poverty; residence characteristics; socioeconomic factors

Abbreviations: CI, confidence interval; HOMA, homeostasis model assessment; MESA, The Multi-Ethnic Study of Atherosclerosis; RD, relative difference.

Recent research has found positive associations between area deprivation and cardiovascular disease (1–3), although mechanisms underlying this association are still poorly understood. Insulin resistance is a precursor to type 2 diabetes (4) and often to coronary heart disease (5, 6). Thus, it may be a mechanism contributing to neighborhood differences in cardiovascular risk.

Although type 2 diabetes and metabolic abnormalities are growing in prevalence, little research has been devoted to understanding environmental determinants of these conditions. Area-level environmental characteristics may affect diet and physical activity—two important risk factors for insulin resistance (7–16). Supermarkets are less prevalent in poor areas (17, 18); food stores in poor neighborhoods are less likely to sell healthier items such as low-fat and high-fiber products (19, 20), and retail supply of healthier foods has been positively associated with diets (21). A growing body of work has documented associations between the

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physical activity of residents and area characteristics such as land-use mix, street connectivity, residential density, and availability of recreational resources (15, 16, 22–27). Thus, there are clear mechanisms through which area environmental characteristics could be related to the development of insulin resistance. To our knowledge, only one study has examined area factors and insulin resistance and found some evidence that neighborhood disadvantage is associated with greater insulin resistance among young adults, even after controlling for individual-level socioeconomic factors (28).

Prior work on area-level exposures and health mostly defined exposure by using the administrative unit within which a person resides (e.g., census tract, ZIP (postal) code), with little attention to the broader spatial context within which the area is located. However, administrative spatial units are of widely varying sizes, residents' exposures to area characteristics likely extend beyond the boundary lines of administrative units, and a person's health may be affected not only by his or her local neighborhood but also by features of a wider surrounding area. In addition, sociologic research has shown that poor areas are worse off if they are surrounded by other poor areas (29). In the case of health, surrounding area deprivation may magnify the local poverty health effect because of spatial isolation from resources associated with wealthy areas.

We examined the cross-sectional relation between area deprivation and insulin resistance in a large population-based sample. In contrast to prior work based on administrative areas, we used spatial analytic techniques to characterize areas of a specific size and multiple-area exposures to investigate possible interactions between local and surrounding areas. First, we hypothesized that insulin resistance is positively related to local neighborhood poverty and distance to a wealthy area. Subhypotheses were that 1) diet and physical activity mediate the relation between area characteristics and insulin resistance (operating partly via body mass index), and 2) persons without access to an automobile and/or of lower socioeconomic status may be less mobile and more vulnerable to the effects of area-level deprivation. Second, we hypothesized that the positive association between local neighborhood poverty and insulin resistance is greatest when the local neighborhood is surrounded by a high-poverty area or when it is far from a wealthy area.

MATERIALS AND METHODS

Sources of data

Person-level data. Data used in these analyses were derived from The Multi-Ethnic Study of Atherosclerosis (MESA), a cohort study of atherosclerosis, and from the 2000 US Census. MESA enrolled 6,814 persons aged 45–84 years at baseline at six field centers: New York and Bronx counties, New York; Baltimore City and County, Maryland; Forsyth County, North Carolina; Chicago, Illinois; St. Paul, Minnesota; and Los Angeles, California. At each site, participants were recruited by using a variety of population-based approaches. Only persons free of clinical cardiovascular disease at baseline were enrolled. Additional details on the design of MESA are provided elsewhere (30). Data used in these analyses were collected at the baseline examination, 2000–2002.

Insulin resistance was measured via the homeostasis model assessment (HOMA) index ([fasting insulin [μU/ml] × fasting glucose [mmol/liter]]/22.5). The HOMA index is well correlated with measures obtained from the "gold-standard" hyperinsulinemic clamp ($R = 0.88$ (31)) and has been widely used in epidemiologic studies to quantify insulin resistance. The HOMA index was log transformed for multivariable analyses because of its skewed distribution and was investigated as a continuous variable.

Information on the person-level covariates age, sex, race/ethnicity, income, education, automobile ownership, physical activity, dietary intake, and body mass index was obtained during the MESA examination. Race/ethnicity was self-reported and classified as Hispanic, non-Hispanic Caucasian, African American, and Asian Chinese. Participants selected their total combined family income for the past 12 months from 13 income categories; continuous family per capita income was calculated by dividing the interval midpoint of family income (in US dollars) by the number of persons supported. Participants selected their education from eight categories; number of continuous years of education was computed from the interval midpoint of the education categories. Because moderate and vigorous physical activity are known to be negatively associated with insulin resistance (15, 16), metabolic equivalent task-minutes for moderate- and vigorous-intensity sports and conditioning activities were estimated from a physical activity questionnaire (30, 32). Because diets higher in fiber and lower in fats have been found to be associated with less insulin resistance (11–14, 33), servings per day of low-fat dairy and high-fiber/low-fat cereals were estimated from a food frequency questionnaire (30).

Area-level data. Census block group poverty and income data for year 2000 were obtained from the Long-Form, Summary File 3a (34). We used percentage of the block group population whose incomes were 150 percent or less of the federal poverty level; it is likely that the federal poverty index underestimated poverty in our urban study areas because of the higher relative cost of basic goods (35).

The following poverty exposures were derived: 1) poverty level in the local neighborhood, 2) poverty level in the area that encircles the local neighborhood, and 3) minimum distance between the participant's residence and a high-income area. To compute these measures, US Census block group poverty data were converted to a raster grid by using a cell size of 20 m^2. Spatial kernel estimation (36, 37), a spatial smoothing technique, was then used to estimate poverty measures for areas of varying size smoothed over space.

We defined the local neighborhood as a 0.25-mile distance (400 m or approximately a five-block radius) from each person's residence. The 0.25-mile distance has been widely used in urban planning literature to specify the scale of residential neighborhoods based on relatively easy walkability (38, 39). Surrounding poverty was defined as average poverty area in the 0.75-mile (1.21 km) buffer that surrounds each person's local neighborhood. Distance to a wealthy area was the Euclidean distance from the participant's residence to the boundary of the nearest block group with per capita income of $33,000 or more; this threshold represents the upper 10 percent of the US distribution and the upper 19 percent of the MESA study site distribution of per-capita block group incomes, respectively.

Of the 6,814 MESA participants at baseline, 6,191 agreed to participate in an ancillary study, the MESA Neighborhood Study (30). Of these persons, 149 were excluded because of address errors; 736 because of missing information on outcome, exposure, or key covariates; and 485 because they used oral hypoglycemic agents or insulin, which would medically alter glucose and/or insulin levels. Therefore, data on 4,821 participants were available for analysis. The demographic characteristics of persons included in the analysis were similar to those of persons who were excluded, except that excluded participants were less likely to be Caucasian (27 percent vs. 43 percent) and had lower income ($22,000 vs. $27,500 per-capita family income) and educational levels (12.1 vs. 13.4 years of education). All MESA participants provided written informed consent.

Statistical analysis

We first examined the distribution of individual-level variables by cross-classified levels of local poverty and distance to a wealthy area. To examine our primary hypothesis, linear ordinary least-squares regression was used to estimate associations of HOMA index with local poverty and distance to a wealthy area—before and after adjustment for age, sex, income, and education. Associations were also examined before and after adjustment for race/ethnicity. To examine subhypotheses regarding mediators, models were examined before and after adjustment for physical activity, dietary variables, and body mass index. To examine our second hypothesis, estimates of local-area poverty were stratified by surrounding-area poverty and by distance to a wealthy area, and interactions were tested by including terms in regression models. Similar methods were used to examine heterogeneity in the effects of area-level variables by selected individual characteristics (body mass index, income, automobile ownership, and race/ethnicity).

In this paper, mean differences in log-HOMA index estimated from linear regression are reported as relative differences (RDs, the exponent of the mean difference) or percent relative difference (RD $\times$ 100). To compare associations of HOMA index with diverse area-level variable units, the estimates shown correspond to differences between the 90th and 10th percentiles of the area-level variable, which translates to a difference of 41 percent in local neighborhood poverty and 4.4 km (2.7 miles) for distance to a wealthy area (e.g., RD = 1.18 means that when local poverty increased from the 10th to the 90th percentile (41 percent), HOMA increased 18 percent). The square-root transformation of distance to a wealthy area was used in multivariable regression analyses because it provided a better fit. Generalized additive models (40) were used to explore nonlinear associations between the independent variables and the outcome variable while adjusting for covariates; nonlinear associations were subsequently fit in ordinary least squares by using linear splines.

Because results from traditional covariance analyses may be biased because of reliance on extrapolated data, we conducted sensitivity analyses by using propensity score matching (41). Persons classified as living in the lowest quartile of neighborhood poverty were tightly matched to those in the highest quartile on variables related to socioeconomic position (log odds between matched pairs differed $\leq$1 percent) (42). Matched-pair *t* tests were used to test for differences in HOMA index. Analogous propensity matching procedures were used to test for differences in HOMA index by distance to a wealthy area while holding local poverty constant, and vice versa.

We examined the sensitivity of results to those obtained when the outcome measure was a combination of impaired fasting glucose and diabetes (43); when alternate measures of area poverty were used (increasing the size of the local neighborhood, increasing and decreasing the size of the surrounding area, and alternate thresholds of wealthy area); and when residual spatial dependence was modeled (44).

RESULTS

Table 1 shows characteristics of the study sample. Mean local neighborhood poverty level 0.25 mile (0.4 km) around the participant's residence was 23 percent. Mean distance between participant residences and wealthy areas was 1.11 mile (1.78 km). Local neighborhood poverty was moderately negatively correlated with family income (Spearman's rank correlation coefficient (r) = −0.36) and individual education ($r = -0.33$) (bivariate correlations not shown in table). Surrounding poverty was highly correlated with local poverty ($r = 0.88$); these high correlations precluded further investigation of the independent effects of local- and surrounding-area poverty. Distance to a wealthy area was moderately positively correlated with neighborhood local poverty ($r = 0.29$). Across the four cross-classified categories, there was a gradient in HOMA index and almost all risk factors, with more adverse risk factor profiles as local poverty and distance to a wealthy area increased.

The HOMA index was positively associated with being female, being Chinese or Hispanic, and body mass index and was inversely associated with education, income, physical activity, and intake of high-fiber and low-fat foods (not shown). The HOMA index was also positively associated with local neighborhood poverty, after adjustment for age, sex, income, and education (table 2, model 4; relative increase in HOMA index = 7 percent, 95 percent confidence interval (CI): 2 percent, 13 percent for a change between the 90th and 10th percentiles of local poverty). The association of local neighborhood poverty with HOMA was only slightly reduced when distance to a wealthy area was added to the model, and both measures remained independently associated with HOMA score, although distance to a wealthy area had a stronger association (model 5, for a change between the 90th and 10th percentiles: RD = 1.05, 95 percent CI: 1.00, 1.11 for local poverty and RD = 1.14, 95 percent CI: 1.09, 1.21 for distance to a wealthy area). The addition of race/ethnicity did not substantially alter the association between distance to a wealthy area and HOMA index,

TABLE 1. Personal characteristics and area characteristics of the full study sample and stratified by local poverty and distance to a wealthy area* (n = 4,821), The Multi-Ethnic Study of Atherosclerosis, United States, 2000–2002

	Full sample	Local poverty <30%		Local poverty ≥30%	
		Close to a wealthy area (<1.2 km or <0.75 miles) (best)	Far from a wealthy area (≥1.2 km or ≥0.75 miles) (better)	Close to a wealthy area (<1.2 km or <0.75 miles) (bad)	Far from a wealthy area (≥1.2 km or ≥0.75 miles) (worst)
Demographic factors					
No. of participants	4,821	1,812	1,532	643	834
Age in years (mean (SD†))	61.57 (10.18)	61.75 (10.10)	60.98 (10.02)	62.03 (10.49)	61.91 (10.34)
Sex: female (%)	52.5	50.8	51.4	55.2	56.1
Race/ethnicity (%)					
Caucasian	43.2	63.0	48.0	15.9	12.5
Chinese	12.9	15.5	6.7	14.3	17.6
African American	23.2	10.8	27.5	33.1	34.7
Hispanic	20.7	10.8	17.8	36.7	35.3
Socioeconomic status					
Family income in US dollars (mean (SD))	27,462 (21,147)	35,603 (23,595)	25,955 (17,797)	21,331 (18,571)	17,271 (15,748)
No. of years of education (mean (SD))	13.4 (3.9)	15.0 (3.1)	13.3 (3.4)	12.2 (4.3)	11.2 (4.7)
Mediators					
Any dietary intake of high-fiber/low-fat cereals‡ (%)	58.2	60.9	57.9	56.0	54.9
Any dietary intake of low-fat dairy products (%)	64.9	67.9	67.5	58.8	58.4
Physical activity§ (%)					
Low	22.2	15.2	23.8	25.2	31.9
Medium	51.8	53.6	50.7	51.3	50.5
High	26.0	31.2	25.5	23.5	17.6
Body mass index in kg/m^2 (mean (SD))	27.93 (5.21)	27.06 (4.93)	28.59 (5.12)	28.01 (5.54)	28.54 (5.43)
Outcome					
Insulin resistance as measured by the HOMA† index (mean (SD))	1.63 (1.44)	1.47 (1.28)	1.73 (1.68)	1.60 (1.21)	1.82 (1.40)
Median value (25th–75th percentile)	1.23 (0.78, 2.00)				
Poverty in the local neighborhood (mean % (SD))	23 (16)	12 (7)	16 (8)	44 (9)	42 (9)
Surrounding area					
Poverty (mean % (SD))	25 (14)	16 (9)	20 (9)	43 (9)	38 (10)
Distance to a wealthy area (mean (SD))					
Kilometers (mean (SD))	1.78 (2.06)	0.24 (0.34)	3.48 (2.28)	0.61 (0.36)	2.90 (1.39)
Miles (mean (SD))	1.11 (1.28)	0.15 (0.21)	2.16 (1.42)	0.38 (0.22)	1.80 (0.87)

* Cutpoints were chosen after examination of plots from adjusted generalized additive models (refer to the text for more details) and consideration of sufficient sample size in the two groups. The cutpoint for local poverty was at the 70th percentile, and the cutpoint for distance to a wealthy area was at the 50th percentile. Global tests of differences across the four categories for each variable listed, using F tests for continuous variables and chi-square tests for categorical variables, had p values of <0.0000, except for age ($p = 0.05$), sex ($p = 0.03$), and high-fiber diet ($p = 0.02$).

† SD, standard deviation; HOMA, homeostasis model assessment.

‡ High-fiber/low-fat breads, cereals, rice, and pasta.

§ Physical activity was categorized on the basis of the 25th and 75th percentiles of the sample distribution.

TABLE 2. Relative differences (with 95% confidence intervals) in the HOMA* index for a change between the 90th and 10th percentiles in area-level characteristics, adjusted for variables (n = 4,821), The Multi-Ethnic Study of Atherosclerosis, United States, 2000–2002

Model no. and variables included†	Adjusted R^2	Local neighborhood poverty per 41% increase		Distance to a wealthy area per 4.4 km (2.7 miles)	
		Relative difference	95% confidence interval	Relative difference	95% confidence interval
Model 1: local poverty	0.01	1.18	1.12, 1.24		
Model 2: distance to a wealthy area	0.01			1.25	1.18, 1.31
Model 3: local poverty, distance to a wealthy area	0.02	1.13	1.07, 1.19	1.21	1.15, 1.28
Model 4: age, sex, income, education, local poverty	0.03	1.07	1.02, 1.13		
Model 5: age, sex, income, education, local poverty, distance to a wealthy area	0.04	1.05	1.00, 1.11	1.14	1.09, 1.21
Model 6: age, sex, income, education, race/ethnicity, local poverty, distance to a wealthy area	0.06	0.97	0.92, 1.03	1.13	1.07, 1.19
Model 7: age, sex, income, education, race/ethnicity, dietary variables, physical activity, local poverty, distance to a wealthy area	0.08	0.96	0.91, 1.02	1.09	1.03, 1.15
Model 8: age, sex, income, education, race/ethnicity, dietary variables, physical activity, body mass index, local poverty, distance to a wealthy area	0.33	0.98	0.93, 1.03	1.05	1.00, 1.10

* HOMA, homeostasis model assessment.

† Linear splines were created for age (knot at 63 years) and education (knot at 11 years). Dietary variables were fit as continuous variables and were adjusted for caloric intake.

although it eliminated the association between local poverty and HOMA index (model 6; RD = 0.97, 95 percent CI: 0.92, 1.03 for local poverty and RD = 1.13, 95 percent CI: 1.07, 1.19 for distance to a wealthy area). Additional adjustment for physical activity and dietary variables increased model fit (adjusted R^2 from 6 percent to 8 percent) and reduced the association between distance to a wealthy area and HOMA index (model 7; RD = 1.09, 95 percent CI: 1.03, 1.15 for distance to a wealthy area). Adjustment for body mass index had a large impact on model fit (model 8; adjusted $R^2 = 33$ percent) and further attenuated the association between distance to a wealthy area and HOMA index (RD = 1.05, 95 percent CI: 1.00, 1.10).

The age-, sex-, income-, and education-adjusted association between neighborhood poverty and HOMA was linear despite a slight increase in the association after reaching poverty levels of 40 percent or more, and the association of distance with HOMA became weaker at distances beyond 2.5 km (15 percent and 26 percent of the sample, respectively; not shown). The association between HOMA index and local poverty became somewhat stronger as surrounding-area poverty increased above 35 percent, although this heterogeneity was not statistically significant ($p = 0.8$) and there was no evidence of heterogeneity in local poverty effects by distance to a wealthy area ($p = 0.6$) (not shown).

The relation between local poverty and HOMA was stronger for persons without an automobile (test for interaction $p = 0.07$, figure 1) and was heterogeneous by income (test for interaction $p = 0.02$), although there was no clear pattern. The relation was stronger for persons of lower body mass index (test for interaction $p = 0.06$) and was stronger for Chinese persons; differences by race/ethnicity were not significant. After adjustment for local poverty and individual-level covariates, the relation between distance to a wealthy area and HOMA was stronger for persons with the lowest incomes (test for interaction $p = 0.03$), but no clear trend across categories was present and was slightly stronger for persons without an automobile (although this interaction was not statistically significant); associations were stronger for Chinese and Hispanic persons (test for interaction $p = 0.02$).

Propensity-score-matched participants were virtually identical across key covariates (not shown), and associations obtained from the matched sample were generally similar to those from the full sample, although of slightly smaller magnitude (table 3). Confidence intervals were wider because of a much smaller sample size.

In the full sample, results were similar when the HOMA index was replaced by a combined outcome of impaired fasting glucose and diabetes (which included persons treated for diabetes) (adjustment for model 6 variables; odds ratio = 1.04, 95 percent CI: 0.88, 1.23 for local poverty and odds ratio = 1.38, 95 percent CI: 1.17, 1.63 for distance to a wealthy area; not shown in table). Results were robust to alternate specifications of the weights used in spatial smoothing, increasing the size of the local area from 0.25 to 0.5 mile, altering the definition of surrounding-area poverty from 0.75 mile to 0.5 and 2 miles, and changing the cutpoint for wealthy areas from the top 10th percentile of US per-capita block group incomes ($33,000) to the top 25th percentile ($25,000). Spatial dependence statistics indicated very weak, but statistically significant dependence among model residuals (Moran's $I = 0.01$, $p = 0.02$) (37, 45), although spatial autocorrelation models yielded very

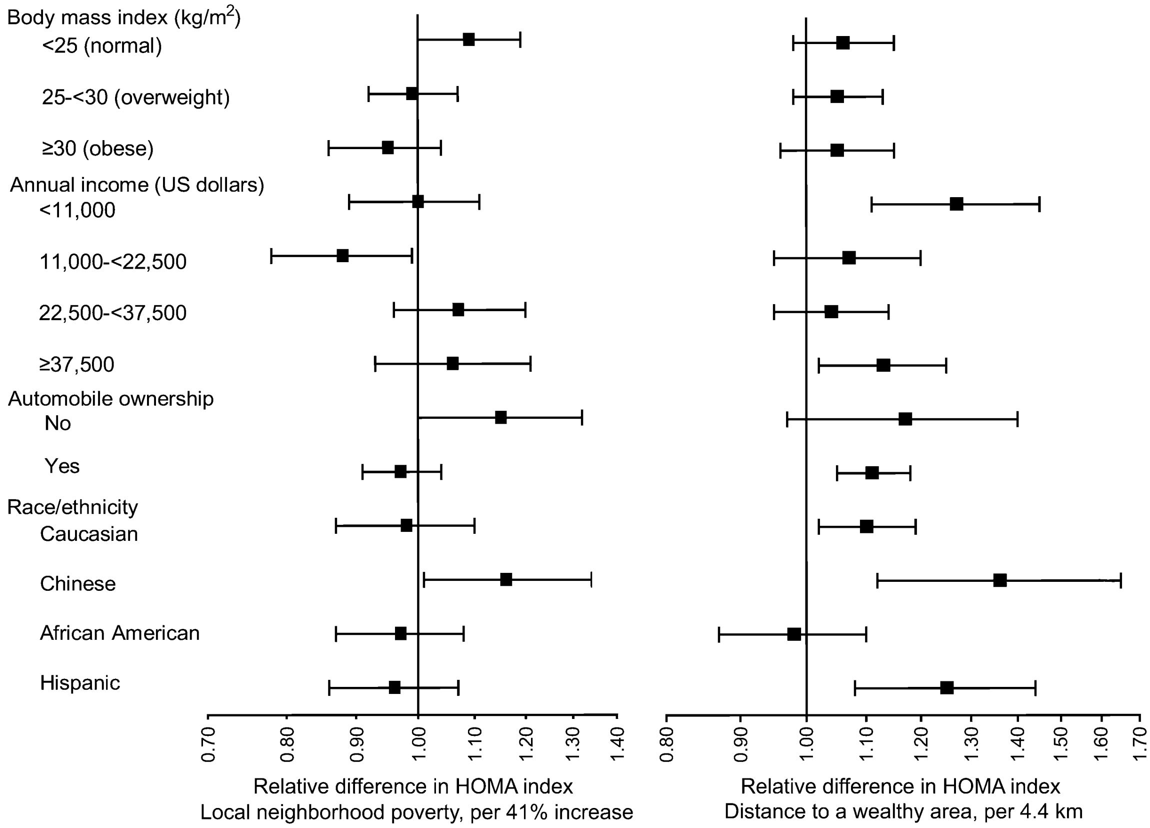

FIGURE 1. Adjusted relative differences in homeostasis model assessment (HOMA) index for a change between the 90th and 10th percentiles of area-level characteristics, stratified by person-level variables, The Multi-Ethnic Study of Atherosclerosis, United States, 2000–2002. Bars, 95% confidence intervals. Results for local neighborhood poverty were adjusted for sex, race/ethnicity, income, and education. Results for distance to a wealthy area were adjusted for age, sex, race/ethnicity, income, education, and local neighborhood poverty. Body mass index was calculated as weight in kilograms divided by height in meters squared.

TABLE 3. Relative mean differences (with 95% confidence intervals) in the HOMA* index between the highest and lowest quartiles of area characteristics for the unrestricted sample and for the propensity-score-matched sample, The Multi-Ethnic Study of Atherosclerosis, United States, 2000–2002

Contrast (lowest vs. highest quartile)	Analogous model from table 2	Unrestricted sample†			Propensity-matched sample‡		
		No. of participants	Relative difference	95% confidence interval	No. of matched pairs	Relative difference	95% confidence interval
Local neighborhood poverty	Model 4	2,411	1.08	1.02, 1.15	393	1.04	0.95, 1.14
Local neighborhood poverty; additional adjustment for distance to a wealthy area and race/ethnicity	Model 6	2,411	0.98	0.91, 1.05	356	0.97	0.88, 1.06
Distance to a wealthy area; additional adjustment for local poverty and race/ethnicity	Model 6	2,411	1.12	1.05, 1.19	475	1.10	1.01, 1.20

* HOMA, homeostasis model assessment.

† Estimates were obtained by regressing log-HOMA index on the binary area-level variable, with age, sex, income, and education as covariates. Additional covariates are specified in the left column for each row.

‡ Propensity-score-matched pairs balanced participants by variables collected at the examination: age, sex, income, participant's education, mother's education, father's education, home ownership, automobile ownership, land ownership, having investments/stocks or bonds, current job status, and marital status. Additional covariates are specified in the left column for each row. The area-level variables used in the propensity score table illustrate the independent effect of one area-level variable while holding constant (matching) on another area-level variable. The propensity-score relative difference is the exponentiated mean difference between the two groups.

similar multivariable results (adjustment for model 6 variables; RD = 0.97, 95 percent CI: 0.91, 1.05 for local poverty and RD = 1.10, 95 percent CI: 1.02, 1.18 for distance to a wealthy area).

DISCUSSION

In this cross-sectional study of adults, distance to a wealthy area was consistently associated with HOMA index, and the association was independent of local poverty and robust to adjustment for person-level variables. Adjusted for age, sex, race/ethnicity, income, and education, the relative increase for a 4.4-km change (2.7 miles, 10th to 90th percentile) in distance to a wealthy area was 13 percent (95 percent CI: 7 percent, 19 percent). This value was roughly equivalent to the adjusted relative difference in HOMA index associated with a 1.7-kg/m^2 increase in body mass index. A one-unit increase in body mass index (from 25 to 26 kg/m^2) has been associated with at least a 14 percent increased risk of diabetes over a 20-year period (46). Results were generally robust when propensity score matching was used as an alternative to regression techniques to control for individual-level measures of socioeconomic position.

These results suggest that proximity to resources in high-income areas may be related to better health. Area affluence is more spatially concentrated than poverty (47), and some research has suggested that area affluence is a better indicator than area poverty of health-enhancing resources (48, 49). Research has found that higher-income areas have more supermarkets and fruits and vegetables (17, 18, 50). More affluent areas may also have more recreational facilities, although such evidence is less clear (51, 52). In our analyses, the association of distance to a wealthy area was reduced after adjustment for diet, physical activity, and body mass index, suggesting that these variables may play a mediating role. However, as in all regression analyses of this type, estimating the percentage of the total effects due to mediating variables is rendered complex by measurement error in the mediators and by the possibility of unmeasured confounders of the association between the mediators and insulin resistance (53, 54).

Local neighborhood poverty was positively associated with insulin resistance, adjusted for person-level age, sex, income, and education in the full sample, but this association was not robust to adjustment for race/ethnicity. Whether estimates of local-area effects should or should not be adjusted for race/ethnicity is debatable. There are several ways through which race/ethnicity may be related to insulin resistance: cultural traditions and preferences that relate to diet and physical activity, genetic influences, or socioeconomic status, which can determine residential location (55–58). Because neighborhoods are spatially patterned by socioeconomic and racial/ethnic composition, it may be difficult or impossible to isolate the independent effects of local poverty and race/ethnicity (59–61). Thus, adjustment for race/ethnicity could result in underestimates of area effects. Because race/ethnicity was less correlated with distance to a wealthy area, estimates of the association between distance to a wealthy area and HOMA index were robust to adjustment for race/ethnicity. Although not hypothesized a priori to be heterogeneous, of note is the stronger association found among Chinese persons between both measures of area deprivation and HOMA index. This finding may have been due to a low body mass index among Chinese persons, among whom relatively weak associations between distal area-level factors and insulin resistance may be more easily detectable.

Prior research has suggested that access to transportation may buffer adverse area effects (62, 63); we also found that the association between insulin resistance and each area measure was stronger for those without an automobile, although this heterogeneity was statistically significant for local poverty only. High personal income may also buffer adverse area effects, although evidence from prior work has been mixed (28, 64, 65). We found that family income was an inconsistent modifier: distance to a wealthy area was more strongly associated with insulin resistance for those with the lowest incomes, but the pattern was not evident for local poverty. Contrary to our hypothesis, there was no clear indication that surrounding poverty or distance to a wealthy area modified the association between local poverty and insulin resistance. Our inability to detect an interaction may have been due to limited sample size in discordant cells or to a generally weak effect of local-area poverty.

A strength of this study is the large, population-based, multiethnic sample. However, exclusion of persons with a history of clinical cardiovascular disease (by design) could have resulted in underestimates of associations because the condition is associated with insulin resistance and may be associated with living in a poor area. Insulin resistance is likely to develop slowly over a long period (66), making long-term past exposures more relevant than current exposures. We could not investigate temporal sequence or time lags in the present cross-sectional study; however, if current residence approximately reflects characteristics of past places of residence, our cross-sectional associations could reflect long-term effects.

An important question is whether the scale relevant for area health effects is likely to be similar across the sites studied, which differ by transportation infrastructure, public investment, and commerce; all may modify area effects. The magnitude of association between insulin resistance and distance to a wealthy area differed somewhat by study area (highest in New York: RD = 1.24, 95 percent CI: 0.92, 1.67; lowest in Forsyth County: RD = 1.06, 95 percent CI: 0.96, 1.17 (not shown)), although differences were not statistically significant.

Identifying causal effects of area factors on insulin resistance is a difficult task, in part because of the complex biologic processes involved and because of the distal relation and time lags between area factors and their biologic consequences. This difficulty makes even the relatively small associations that we report striking. Recent increases in type 2 diabetes highlight the public health importance of identifying environmental risk factors for this disorder. Our results suggest that future strategies may need to include reductions in concentrated poverty and bringing to poorer areas the services and physical amenities that may be available in wealthy areas. Next steps are to better specify which environmental factors increase the prevalence of metabolic abnormalities to build a stronger case for altering community-level environmental risks and improving material features of places.

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A. H. Auchincloss designed the study, conducted all analyses, and drafted the paper. A. V. Diez Roux contributed to the conceptualization of the study, interpreted findings, and wrote sections of the paper. D. G. Brown contributed to the conceptualization of the area-level measures, interpreted findings, and provided comments on drafts. E. S. O'Meara assisted with primary data collection/management and provided comments on drafts. T. E. Raghunathan assisted with conceptualizing statistical analyses and provided comments on drafts.

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REFERENCES

1. Diez-Roux AV, Nieto FJ, Muntaner C, et al. Neighborhood environments and coronary heart disease: a multilevel analysis. Am J Epidemiol 1997;146:48–63.
2. Cubbin C, Hadden WC, Winkleby MA. Neighborhood context and cardiovascular disease risk factors: the contribution of material deprivation. Ethn Dis 2001;11:687–700.
3. Diez Roux AV, Merkin SS, Arnett D, et al. Neighborhood of residence and incidence of coronary heart disease. N Engl J Med 2001;345:99–106.
4. Hanley AJ, Karter AJ, Williams K, et al. Prediction of type 2 diabetes mellitus with alternative definitions of the metabolic syndrome: the Insulin Resistance Atherosclerosis Study. Circulation 2005;112:3713–21.
5. Hanley AJ, Williams K, Stern MP, et al. Homeostasis model assessment of insulin resistance in relation to the incidence of cardiovascular disease: the San Antonio Heart Study. Diabetes Care 2002;25:1177–84.
6. Bonora E, Formentini G, Calcaterra F, et al. HOMA-estimated insulin resistance is an independent predictor of cardiovascular disease in type 2 diabetic subjects: prospective data from the Verona Diabetes Complications Study. Diabetes Care 2002;25: 1135–41.
7. Hu FB, van Dam RM, Liu S. Diet and risk of type II diabetes: the role of types of fat and carbohydrate. Diabetologia 2001; 44:805–17.
8. Bazzano LA, Serdula M, Liu S. Prevention of type 2 diabetes by diet and lifestyle modification. J Am Coll Nutr 2005;24:310–19.
9. Thanopoulou AC, Karamanos BG, Angelico FV, et al. Dietary fat intake as risk factor for the development of diabetes: multinational, multicenter study of the Mediterranean Group for the Study of Diabetes (MGSD). Diabetes Care 2003;26:302–7.
10. Meyer KA, Kushi LH, Jacobs DR Jr, et al. Dietary fat and incidence of type 2 diabetes in older Iowa women. Diabetes Care 2001;24:1528–35.
11. Hung T, Sievenpiper JL, Marchie A, et al. Fat versus carbohydrate in insulin resistance, obesity, diabetes and cardiovascular disease. Curr Opin Clin Nutr Metab Care 2003;6:165–76.
12. Liese AD, Roach AK, Sparks KC, et al. Whole-grain intake and insulin sensitivity: the Insulin Resistance Atherosclerosis Study. Am J Clin Nutr 2003;78:965–71.
13. McKeown NM, Meigs JB, Liu S, et al. Carbohydrate nutrition, insulin resistance, and the prevalence of the metabolic syndrome in the Framingham Offspring Cohort. Diabetes Care 2004;27:538–46.
14. Schulz M, Liese AD, Mayer-Davis EJ, et al. Nutritional correlates of dietary glycaemic index: new aspects from a population perspective. Br J Nutr 2005;94:397–406.
15. Laaksonen DE, Lakka HM, Niskanen LK, et al. Metabolic syndrome and development of diabetes mellitus: application and validation of recently suggested definitions of the metabolic syndrome in a prospective cohort study. Am J Epidemiol 2002;156:1070–7.
16. Hu G, Lindstrom J, Valle TT, et al. Physical activity, body mass index, and risk of type 2 diabetes in patients with normal or impaired glucose regulation. Arch Intern Med 2004;164:892–6.
17. Morland K, Wing S, Diez Roux A, et al. Neighborhood characteristics associated with the location of food stores and food service places. Am J Prev Med 2002;22:23–9.
18. Zenk SN, Schulz AJ, Israel BA, et al. Neighborhood racial composition, neighborhood poverty, and the spatial accessibility of supermarkets in metropolitan Detroit. Am J Public Health 2005;95:660–7.
19. Horowitz CR, Colson KA, Hebert PL, et al. Barriers to buying healthy foods for people with diabetes: evidence of environmental disparities. Am J Public Health 2004;94:1549–54.
20. Lewis LB, Sloane DC, Nascimento LM, et al. African Americans' access to healthy food options in South Los Angeles restaurants. Am J Public Health 2005;95:668–73.
21. Fisher BD, Strogatz DS. Community measures of low-fat milk consumption: comparing store shelves with households. Am J Public Health 1999;89:235–7.
22. Sallis JF, Hovell MF, Hofstetter CR, et al. Distance between homes and exercise facilities related to frequency of exercise among San Diego residents. Public Health Rep 1990;105:179–85.
23. Humpel N, Owen N, Leslie E. Environmental factors associated with adults' participation in physical activity: a review. Am J Prev Med 2002;22:188–99.
24. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med 2004;27:87–96.
25. Badland H, Schofield G. Transport, urban design, and physical activity: an evidence-based update. Transportation Res Part D Transport Environ 2005;10:177–96.
26. Frank LD, Schmid TL, Sallis JF, et al. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. Am J Prev Med 2005; 28(suppl 2):117–25.
27. Li F, Fisher KJ, Brownson RC, et al. Multilevel modelling of built environment characteristics related to neighbourhood walking activity in older adults. J Epidemiol Community Health 2005;59:558–64.
28. Diez Roux AV, Jacobs DR, Kiefe CI. 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;25:1976–82.
29. Massey DS, Fischer MJ. How segregation concentrates poverty. Ethn Racial Stud 2000;23:670–91.
30. Bild DE, Bluemke DA, Burke GL, et al. Multi-Ethnic Study of Atherosclerosis: objectives and design. Am J Epidemiol 2002;156:871–81.
31. Matthews DR, Hosker JP, Rudenski AS, et al. Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 1985;28:412–19.
32. 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(suppl):S498–504.
33. Ludwig DS. Diet and development of the insulin resistance syndrome. Asia Pac J Clin Nutr 2003;12(suppl):S4.
34. US Bureau of the Census. Census of population and housing, 2000: summary tape file 3. Washington, DC: Bureau of the Census, US Department of Commerce, 2000. (CD-ROM, machine-readable data files).
35. Citro CF, Michael RT, eds. Measuring poverty: a new approach. Washington, DC: National Academy Press, 1995.
36. Waller LA, Gotway CA. Applied spatial statistics for public health data. Hoboken, NJ: Wiley, 2004.
37. Bailey TC, Gatrell AC. Interactive spatial data analysis. Hoboken, NJ: Wiley, 1995.
38. Perry C. The neighborhood unit. Regional plan of New York and its environs, regional survey. Vol vii. Neighborhood and community planning. New York, NY: Regional Planning Association, 1929.
39. Krizek KJ. Neighborhood services, trip purpose, and tour-based travel. Transportation 2003;30:387–410.
40. Hastie TJ. Generalized additive models. In: Chambers J, Hastie T, eds. Statistical models in S. Pacific Grove, CA: Wadsworth & Brooks/Cole, 1992:249–308.
41. D'Agostino RB Jr. Propensity score methods for bias reduction in the comparison of a treatment to a non-randomized control group. Stat Med 1998;17:2265–81.
42. Martin BC, Ganguly R. SAS program for propensity score matching. Athens, GA: College of Pharmacy, University of Georgia, 2003. (http://www.rx.uga.edu/main/home/cas/faculty/propensity.pdf).
43. Genuth S, Alberti KG, Bennett P, et al. Follow-up report on the diagnosis of diabetes mellitus. Diabetes Care 2003;26:3160–7.
44. Littell R, Milliken G, Stroup W, et al. SAS system for mixed models. Cary, NC: SAS Institute, Inc, 1996.
45. Anselin L, Syabri I, Kho Y. GeoDa: an introduction to spatial data analysis. Geogr Anal 2006;38:5–22.
46. Resnick HE, Valsania P, Halter JB, et al. Differential effects of BMI on diabetes risk among black and white Americans. Diabetes Care 1998;21:1828–35.
47. Massey DS. The age of extremes: concentrated affluence and poverty in the twenty-first century. Demography 1996;33:395–412; discussion 413–396.
48. Wen M, Browning CR, Cagney KA. Poverty, affluence, and income inequality: neighborhood economic structure and its implications for health. Soc Sci Med 2003;57:843–60.
49. Browning CR, Cagney KA. Moving beyond poverty: neighborhood structure, social processes, and health. J Health Soc Behav 2003;44:552–71.
50. Moore LV, Diez Roux AV. Associations of neighborhood characteristics with the location and type of food stores. Am J Public Health 2006;96:325–31.
51. Giles-Corti B, Macintyre S, Clarkson JP, et al. Environmental and lifestyle factors associated with overweight and obesity in Perth, Australia. Am J Health Promot 2003;18:93–102.
52. Estabrooks PA, Lee RE, Gyurcsik NC. Resources for physical activity participation: does availability and accessibility differ by neighborhood socioeconomic status? Ann Behav Med 2003;25:100–4.
53. Cole SR, Hernan MA. Fallibility in estimating direct effects. Int J Epidemiol 2002;31:163–5.
54. Blakely T. Commentary: estimating direct and indirect effects—fallible in theory, but in the real world? Int J Epidemiol 2002;31:166–7.
55. Lee ZS, Critchley JA, Chan JC, et al. Obesity is the key determinant of cardiovascular risk factors in the Hong Kong Chinese population: cross-sectional clinic-based study. Hong Kong Med J 2000;6:13–23.
56. Chan JC, Ng MC, Critchley JA, et al. Diabetes mellitus—a special medical challenge from a Chinese perspective. Diabetes Res Clin Pract 2001;54(suppl 1):S19–27.
57. Caballero AE. Diabetes in the Hispanic or Latino population: genes, environment, culture, and more. Curr Diabetes Rep 2005;5:217–25.
58. Palaniappan LP, Carnethon MR, Fortmann SP. Heterogeneity in the relationship between ethnicity, BMI, and fasting insulin. Diabetes Care 2002;25:1351–7.
59. Diez Roux AV. Multilevel analysis in public health research. Annu Rev Public Health 2000;21:171–92.
60. Oakes JM. The (mis)estimation of neighborhood effects: causal inference for a practicable social epidemiology. Soc Sci Med 2004;58:1929–52.
61. Subramanian SV. The relevance of multilevel statistical methods for identifying causal neighborhood effects. (Commentary). Soc Sci Med 2004;58:1961–7.
62. Macintyre S. The social patterning of exercise behaviours: the role of personal and local resources. Br J Sports Med 2000;34:6.
63. Bostock L. Pathways of disadvantage? Walking as a mode of transport among low-income mothers. Health Soc Care Community 2001;9:11–18.
64. Haan M, Kaplan GA, Camacho T. Poverty and health: prospective evidence from the Alameda County Study. Am J Epidemiol 1987;125:989–98.
65. Yen IH, Kaplan GA. Neighborhood social environment and risk of death: multilevel evidence from the Alameda County Study. Am J Epidemiol 1999;149:898–907.
66. Lyssenko V, Almgren P, Anevski D, et al. Predictors of and longitudinal changes in insulin sensitivity and secretion preceding onset of type 2 diabetes. Diabetes 2005;54:166–74.