International Journal of Obesity (2019) 43:1601–1610
https://doi.org/10.1038/s41366-019-0322-3

ARTICLE

Epidemiology and Population Health

Neighborhood racial/ethnic segregation and BMI: A longitudinal analysis of the Multi-ethnic Study of Atherosclerosis

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Received: 8 April 2018 / Revised: 10 August 2018 / Accepted: 19 September 2018 / Published online: 22 January 2019

Abstract

Background Current knowledge regarding the relationship between segregation and body weight is derived mainly from cross-sectional data. Longitudinal studies are needed to provide stronger causal inference.

Methods We use longitudinal data from the Multi-Ethnic Study of Atherosclerosis and apply an econometric fixed-effect strategy, which accounts for all time-invariant confounders, and compare results to conventional cross-sectional analyses. We examine the relationship between neighborhood-level racial/ethnic segregation, neighborhood poverty, and body mass index (BMI) separately for blacks, Hispanics, and whites. Segregation*gender interactions are included in all models. Neighborhood segregation was operationalized by the local G_i^* statistic, which assesses the extent to which a neighborhood's racial/ethnic composition is under (G_i^* statistic < 0) or over (G_i^* statistic > 0) represented, given the composition in the broader (e.g., county) area. For black, Hispanic, and white stratified models, the G_i^* statistic reflects the level of black, Hispanic, and white segregation, respectively. The G_i^* statistic was scaled such that a unit change represents a 1.96 difference in the score.

Results Cross-sectional models indicated higher segregation to be negatively associated with BMI for white females and positively associated for Hispanic females. No association was found for black females or males in general. In contrast, fixed-effect models adjusting for neighborhood poverty, higher segregation was positively associated with BMI for black females (coeff = 0.25 kg/m^2; 95% CI = [0.03, 0.46]; p-value = 0.03) but negatively associated for Hispanic females (coeff = −0.17 kg/m^2; 95% CI = [−0.33, −0.01]; p-value = 0.04) and Hispanic males (coeff = −0.20; 95% CI = [−0.39, −0.01]; p-value = 0.04). Further controls for socioeconomic factors fully explained the associations for Hispanics but not for black females.

Conclusions Fixed-effect results suggest that segregation's impacts might not be universally harmful, with possible null or beneficial impacts, depending on race/ethnicity. The persistent associations after accounting for neighborhood poverty indicate that the segregation–BMI link may operate through different pathways other than neighborhood poverty.

Introduction

Obesity is an epidemic in the US, with over 60% of the US adult population either overweight or obese. The health ramifications include higher rates of overall mortality and elevated risks for several causes of death [1–3]. With higher rates of overweight and obesity than non-Hispanic whites, Hispanics, and non-Hispanic blacks are disproportionately impacted by the health problems linked to excessive weight [1, 4]. The racial/ethnic differences in weight distributions are only partially accounted for by individual-level factors, such as socioeconomic status and health behaviors [5, 6], suggesting that broader social and economic factors also patterned by race/ethnicity should be examined.

Racial residential segregation in the US, by spatially patterning resources and hazards, is linked to various health outcomes, including mortality, birthweight, self-rated health, and cardiovascular disease and risk factors [7–9]. Consistent evidence demonstrates that higher black segregation is associated with increased mortality risk and adverse birth outcomes for blacks [7]. However, relatively

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few studies have examined body weight and current evidence is mixed, with some studies finding positive associations [10–12] and others finding none [6, 13]. Detrimental associations between segregation and health for blacks are often interpreted as stemming from structural racism that has relegated blacks to areas characterized by adverse environmental features. In contrast, some studies have suggested that Hispanic segregation is associated with stronger social cohesion and networks, as well as protective effects against discrimination and adoption of harmful health behaviors—though debates remain [14–17]. Findings regarding Hispanic segregation and various health outcomes has also been mixed, with results of studies examining body weight finding mainly null [11, 13] or deleterious associations [12, 18, 19].

Several limitations to the current literature are worth noting. First, the overwhelming evidence of a segregation–body weight relationship is based on cross-sectional studies examining blacks, limiting not only causal inference but also our understanding of segregation's impact for other racial/ethnic groups. Second, studies investigating local (neighborhood) level segregation have tended to utilize very crude proxy measures of segregation (e.g., %black), which only capture the racial composition of a neighborhood without taking into account the broader context of the racial/ethnic composition of the metropolitan. For example, neighborhoods with the same racial composition (e.g., 50% black) may be markedly different in Detroit, where blacks represent over 80% of the population, versus in Los Angeles, where blacks represent only 10% of the population [20, 21]. The different social, political, and economic forces driving the racial composition of these neighborhoods may result in very different physical and social contexts. Hence, neighborhoods with the same level of minority racial composition across different cities might not be comparable in social and physical characteristics, potentially leading to non-trivial measurement error.

Lastly, extant segregation studies examining body weight have seldom assessed the role of neighborhood poverty, which has been found to be consistently linked to body weight (cf., [11, 19, 22]). Residential segregation of racial/ethnic minorities is argued to spatially concentrate poverty [23, 24], resulting in minorities residing in areas of higher deprivation, which are characterized by features that are barriers to physical activity and a healthy diet, including lower safety and less access to supermarkets and recreational facilities [25–29]. This gap is noteworthy because, despite being conceptualized as one of the primary pathways through which segregation impacts health, the role of neighborhood poverty vis a vis the segregation–health relationship has seldom been examined. Understanding whether neighborhood poverty is a strong mediator is critical for designing effective health policy interventions.

In response to these gaps, our study (1) uses longitudinal data and applies an econometric fixed-effect strategy to examine the relationship between racial/ethnic segregation and body mass index (BMI) for blacks, Hispanics, and whites; and (2) examines whether segregation influences BMI independent of neighborhood poverty.

Methods

Data

Analyses were based on data from the Multi-Ethnic Study of Atherosclerosis (MESA), a longitudinal study designed to examine the determinants of subclinical cardiovascular disease among men and women aged 45–84 years. Chinese, Hispanic, black, and white participants without clinical cardiovascular disease at baseline were recruited from six sites (New York, NY; Baltimore City and County, MD; Forsyth County, NC; St. Paul, MI; Chicago, IL; and Los Angeles County, CA). The study is composed of five waves of examinations across 12 years: (baseline) examination 1 (2000–2002), examination 2 (2002–2004), examination 3 (2004–2005), examination 4 (2005–2007), and examination 5 (2010–2012). The analytical sample was restricted to those who participated in the MESA Neighborhood Ancillary study and had geocoded addresses ($n = 6163$). Because of the small sample size of Chinese participants, analyses were restricted to Hispanics, non-Hispanic blacks, and non-Hispanic whites ($n = 5439$). Hispanics in the North Carolina study site were excluded due to low numbers ($n = 3$). Participants missing data on model variables were excluded from analyses, resulting in an analytical sample size of 5306.

Health outcome

Our outcome is a continuous measure of BMI (kg/m^2), calculated from weight and height information collected at Exams 1–5 using a balance-beam scale and a stadiometer, respectively.

Racial residential segregation

We utilize a spatial measure of local (neighborhood/tract-level) racial/ethnic residential segregation, operationalized as the local G_i^* statistic. Detailed description of the G_i^* statistic calculation for the MESA study has been described elsewhere [9]. Briefly, neighborhood-level G_i^* statistics were calculated separately for blacks, Hispanics, and whites based on the geocoded addresses of MESA participants that were linked to US Census data (Census 2000 for Exams 1–2; American Community Survey (ACS) 2005–2009 5-year aggregate for Exams 3–4; ACS 2007–2011 for Exam 5). The G_i^* statistic is a spatially-weighted z-score that assesses the degree to which a particular racial/ethnic group in that neighborhood is under or over represented, compared to the overall level of the same racial/ethnic group in the broader area (i.e., the set of counties represented in each MESA site) [30]. By using each county's racial composition as the reference, the G_i^* statistic allows for more valid comparisons of racial segregation levels across sites. Values higher/lower than 1.96 reflect statistically significant clustering/under-clustering while values closer to 0 represent racial/ethnic integration. G_i^* statistic measures were scaled such that a unit change represents a 1.96 difference in the score.

Neighborhood poverty

Neighborhood poverty is defined as the proportion of residents in a Census tract whose income falls below the federal poverty level.

Covariates

Individual-level time-invariant characteristics, collected at baseline, include: gender, nativity (foreign born or US born for Hispanics only), age, years of residence in a respondent's current neighborhood, education (continuous), and primary language spoken (Spanish or English, for Hispanics only). Years of education was computed from the interval midpoint of participants' education category [31].

Time-varying covariates include wealth, household per capita income, labor force status (working at least part time, not working, retired), marital status (married/living with a partner, not married), smoking status (current, former, never smoker), cancer diagnosis (yes, no), and years since baseline. Wealth is a four point index ranging from 0 (no assets) to 4 (reflecting all four assets: owning one or more car, owning a home or paying a mortgage on a home, owning land, or owning an investment (e.g., stocks, bonds, mutual funds, retirement investments)) [32]. Household per capita income is the total family income (midpoint of income category) divided by the number of persons supported. Cancer diagnosis was defined as having either a hospitalization due to cancer based on ICD-9 code or self-reported doctor diagnosis of cancer.

Analytical strategy

Because residential segregation may mean different things for different racial/ethnic groups, all models are stratified by race/ethnicity. For the black stratified models, the G_i^* statistics reflect the level of black segregation; for the Hispanic stratified models, the G_i^* statistics reflect the level of Hispanic segregation; and for the white stratified models, the G_i^* statistics reflect the level of white segregation. Additionally, all models include interactions between gender and the G_i^* statistic to allow for the relationship between segregation and BMI to vary between males and females.

We estimated a series of regression models utilizing two strategies to investigate the link between local racial/ethnic segregation and BMI. Our first set of models examines the relationship between baseline neighborhood segregation and baseline BMI. All covariates reflect values as measured in Exam 1. These specifications replicate the standard cross-sectional analysis strategy in the literature and serve as a base of comparison.

The rationale for our cross-sectional model sequence is to initially examine the relationship between segregation and BMI, adjusting only for characteristics that could not be influenced by segregation: age, gender, nativity, length of residence (Model 1). We then add neighborhood poverty to examine whether neighborhood poverty confounds or mediates the relation between segregation and BMI (Model 2). The last model specification adjusts for possible individual characteristics that may confound the relationship between segregation and BMI. However, it should be kept in mind that these modifiable individual-level characteristics, such as income and education, may have been influenced by individuals' past exposures to segregation. Consequently, these characteristics may also be partial mediators as well as confounders. While the above model specifications are common in extant cross-sectional analyses, inferences are tenuous as they are subject to bias from various sources, including omission of unobserved factors.

To mitigate possible omitted variable bias in cross-sectional analyses, our second set of models estimates a series of longitudinal (econometric) fixed-effect analyses estimating the relationship between segregation at year (t) and BMI at year (t). This temporal specification assumes that segregation and its influence on body weight are contemporaneous. While estimating mixed-models is a common strategy for longitudinal neighborhood-health analyses, it rests on the strong assumption that there is no unobserved factor that is correlated with segregation and BMI. For example, if individuals who prefer to reside in highly segregated neighborhoods also tend to have preferences to engage in health behaviors that lend themselves to higher or lower BMI, neglecting to account for this factor in mixed-models may result in spuriously inferring a link between neighborhood segregation and BMI. In other words, causal inference from mixed model rests on the same untestable assumption that conventional cross-sectional analyses do— namely that there is no omitted variable bias due to unobserved confounding. To attenuate possible bias due to omission of variables, we exploit the panel nature of MESA and employ an econometric fixed-effect strategy. The fixed-effect models utilize only the within-person variation to estimate the relationship between segregation and BMI. In the context of this study, the sources of variation in segregation levels might include neighborhood changes across time, as well as residential moves. By relying only on the intra-person variation, the fixed-effect model effectively uses each person as its own control and consequently accounts for each person's unique attribute—whether observed or unobserved—as long as it is time invariant [33–35]. In other words, the fixed-effect estimate automatically adjusts for readily collected characteristics, such as race/ethnicity and sex as well as for more difficult to measure characteristics, such as genetic health disposition and propensity to engage in specific health behaviors. Although it does not address time-varying unobserved confounding, by automatically accounting for all stable individual-level factors, the fixed-effect strategy, compared to a mixed model analysis, is less likely to violate the assumption of no unobserved confounding.

The sequence for our fixed-effect models follows the same rationale as our cross-sectional analysis. First, we adjust only for characteristics that are not likely to be influenced by segregation, including years since baseline to account for aging (Model 1). Second, we add neighborhood poverty (Model 2). Third, we include individual-level time-varying factors that may have been influenced by segregation (Model 3). In order to allow for different BMI trajectories, all fixed-effect models include interactions between all baseline non-time-varying characteristics and time. Since all time-invariant characteristics of each individual (e.g., gender, nativity) are automatically accounted for in fixed-effect estimates, they do not need to be explicitly included in the model specifications.

Results

Table 1 presents descriptive statistics on selected characteristics, measured at baseline, by race/ethnicity and G_i^* statistic level (low: <0; medium: $\geq$0 and $\leq$1.96; high: > 1.96). The high category reflects statistically significant clustering at $p < 0.05$ and the low category reflects statistically significant (G_i^* statistic < −1.96) as well as non-significant under clustering. The low category included both significant and non-significant under clustering because of the small sample of blacks and Hispanics who reside in significantly underrepresented neighborhoods.

For blacks and Hispanics, higher segregation is associated with higher neighborhood poverty. While the average BMI levels do not vary significantly across black or Hispanic segregation levels, black and Hispanic residents in more segregated neighborhoods tend to have lower levels of education and wealth, are less likely to be employed, and have longer duration of residential tenure. Black residents in highly segregated neighborhoods also are more likely to be unmarried while marital status among Hispanics does not vary across segregation levels. Further, Hispanics who reside in high-segregated neighborhoods disproportionately speak Spanish and are foreign born. Whites tend to reside in neighborhoods characterized by low or medium segregation. Higher segregated neighborhoods for whites is associated with lower neighborhood poverty and BMI levels, as well as higher levels of education and income. White residents of more racially mixed neighborhoods (medium segregation) have the highest wealth levels.

Table 2 presents results for cross-sectional models using baseline MESA data. Model 1, which adjusted only for gender, age, nativity, and length of residence, found no association between segregation and BMI for either black females or black males. For Hispanic females, a 1.96 higher G_i^* statistic is associated with a 0.29 kg/m^2 higher BMI. Adjusting for neighborhood poverty (Model 2) attenuated the relationship, but the association between segregation and BMI remained statistically significant in the fully adjusted model (Model 3). In contrast, an inverse association was found for white females such that a 1.96 increase in the G_i^* statistic is linked to a 0.48 kg/m^2 lower BMI in the baseline model. Adjusting for neighborhood poverty and individual attributes does not substantially change the magnitude of the relationship. No association was found for males in general. To put the magnitude of the estimates in context, results from the fully adjusted model also indicated that each $10,000 increase in income is associated with a 0.15 and 0.17 kg/m^2 lower BMI for Hispanic and white women, respectively (results not presented for brevity). Hence, a 1.96 increase in the G_i^* statistic for Hispanic females is associated with a comparable magnitude of BMI increase as a $20,000 reduction in income.

The cross-sectional model results also suggest that, controlling for segregation, higher neighborhood poverty is consistently associated with higher BMI for black females. No significant association was found for other racial/ethnic groups or males in general.

Table 3 presents results from the longitudinal fixed-effects analyses. These models automatically adjust for all non-time varying factors, whether observed or unobserved. Because our original specification, which allowed for varying BMI trajectories by segregation levels, found no evidence of differences in BMI trajectories, we specified a more parsimonious specification and re-estimated all models, dropping the G_i^* statistic*years interaction term. Estimates for segregation and poverty were virtually unchanged. Hence, for simplicity, estimates in Table 3 reflect results from the more parsimonious models.

In contrast to the results from the cross-sectional analyses, higher black segregation was positively associated with BMI for black females such that a 1.96 increase in the

Table 1 Baseline characteristics (proportion or mean value) by race/ethnicity and G^*statistic level: Multi-Ethnic Study of Atherosclerosis, 2000–2011

	Black				Hispanic				White			
	Low < 0	Medium ≥0 & ≤1.96	High > 1.96	*p*-value	Low < 0	Medium ≥0 & ≤1.96	High > 1.96	*p*-value	Low < 0	Medium ≥0 & ≤1.96	High > 1.96	*p*-value
N	270	372	986		250	221	839		1108	994	266	
Body mass index (kg/m^2)	29.91 (5.23)	30.37 (5.78)	30.07 (5.83)	0.56	29.41 (5.35)	28.96 (4.47)	29.70 (5.23)	0.16	28.12 (5.25)	27.58 (4.76)	26.39 (4.84)	<0.01
Neighborhood poverty	11.65 (11.90)	17.20 (12.14)	22.91 (11.85)	<0.01	10.84 (9.09)	15.97 (10.86)	25.84 (11.01)	<0.01	14.50 (7.77)	6.05 (4.25)	7.25 (2.47)	<0.01
Age	60.03 (9.27)	60.14 (9.17)	62.71 (10.23)	<0.01	61.71 (10.30)	61.08 (10.24)	61.25 (10.29)	0.77	60.94 (10.18)	63.64 (10.05)	62.56 (9.62)	<0.01
Female	55.93	54.57	54.56	0.92	49.60	48.87	53.52	0.33	52.89	49.70	53.01	0.30
Years of education	14.46 (2.93)	13.75 (2.94)	13.54 (3.04)	<0.01	12.33 (3.82)	10.05 (4.53)	9.19 (4.70)	<0.01	14.56 (2.83)	14.67 (2.63)	16.00 (2.63)	<0.01
Household per capita income ($10,000)	3.13 (1.87)	2.64 (1.78)	2.46 (1.76)	<0.01	2.23 (1.78)	1.71 (1.38)	1.30 (1.12)	<0.01	3.14 (2.02)	3.71 (2.28)	5.06 (2.50)	<0.01
Wealth index	2.58 (1.22)	2.62 (1.12)	2.33 (1.27)	<0.01	2.07 (1.32)	1.90 (1.32)	1.44 (1.14)	<0.01	2.91 (0.92)	3.14 (0.81)	2.69 (1.13)	<0.01
Employment status				<0.01				0.04				<0.01
Not working/ homemaker	7.41	6.99	11.56		15.60	15.84	21.93		10.38	14.99	8.27	
Retired	29.26	29.57	38.34		29.20	32.13	31.82		27.98	31.39	28.20	
Currently working	63.33	63.44	50.10		55.20	52.04	46.25		61.64	53.62	63.53	
Language: Spanish	0.00	0.00	0.00		33.20	45.25	61.03		0.00	0.00	0.38	0.02
Foreign born					56.40	59.28	72.35	<0.01				
Currently married	55.19	55.38	41.89	<0.01	61.20	58.82	61.03	0.82	62.18	74.85	59.02	<0.01
Diagnosed with cancer	5.56	4.57	6.29	0.47	9.20	6.33	3.34	<0.01	9.84	14.29	16.54	<0.01
Smoking status				0.08				0.03				0.01
Never	50.74	47.58	42.29		49.60	56.11	54.47		43.05	46.68	42.86	
Former	33.70	36.29	38.13		40.80	31.67	30.87		44.22	43.66	50.38	
Current	15.56	16.13	19.57		9.60	12.22	14.66		12.73	9.66	6.77	
Years lived in neighborhood	14.93 (11.85)	15.97 (11.51)	22.51 (14.26)	<0.01	17.89 (12.69)	17.86 (13.91)	19.28 (14.49)	0.22	23.29 (15.65)	17.55 (14.15)	21.67 (12.50)	<0.01
Study site				<0.01				<0.01				<0.01
Wake Forest	54.81	43.82	11.36		0.00	0.00	0.00		9.48	41.35	0.00	
Columbia	31.48	13.98	20.69		29.60	23.98	37.90		5.87	1.11	49.25	
Johns Hopkins	8.52	34.14	31.03		0.00	0.00	0.00		20.58	21.23	3.38	
UMN	0.00	0.00	0.00		34.40	35.75	27.89		40.61	11.37	0.00	
Northwestern	2.59	5.11	24.85		0.00	0.00	0.00		17.60	19.42	46.99	
UCLA	2.59	2.96	12.07		36.00	40.27	34.21		5.87	5.53	0.38	

p-values reflect two-sided tests

Table 2 Estimates of the associations of baseline segregation or poverty with baseline BMI by race/ethnicity: Multi-Ethnic Study of Atherosclerosis, 2000–2011

	Model 1		Model 2		Model 3	
	Estimate (95% CI)	*p*-value	Estimate (95% CI)	*p*-value	Estimate (95% CI)	*p*-value
Black female						
G_i^* statistic	0.04 (−0.23, 0.31)	0.77	−0.05 (−0.34, 0.23)	0.71	−0.08 (−0.36, 0.20)	0.58
Neighborhood poverty			0.54 (0.14, 0.95)	0.01	0.49 (0.08, 0.90)	0.02
Black male						
G_i^* statistic	−0.10 (−0.33, 0.13)	0.39	−0.05 (−0.29, 0.20)	0.70	−0.08 (−0.31, 0.16)	0.53
Neighborhood poverty			−0.29 (−0.62, 0.04)	0.09	−0.32 (−0.67, 0.04)	0.08
Hispanic female						
G_i^* statistic	0.29 (0.07, 0.51)	0.01	0.25 (0.00, 0.51)	0.05	0.27 (0.01, 0.53)	0.04
Neighborhood poverty			0.13 (-0.40, 0.66)	0.63	0.07 (−0.47, 0.61)	0.79
Hispanic male						
G_i^* statistic	0.06 (−0.11, 0.22)	0.49	−0.02 (−0.24, 0.20)	0.87	−0.01 (−0.23, 0.21)	0.93
Neighborhood poverty			0.25 (−0.17, 0.67)	0.25	0.15 (−0.27, 0.57)	0.47
White female						
G_i^* statistic	−0.48 (−0.76, −0.19)	<0.01	−0.53 (−0.86, −0.20)	<0.01	−0.50 (−0.81, −0.19)	<0.01
Neighborhood poverty			−0.12 (−0.74, 0.50)	0.71	−0.20 (−0.83, 0.43)	0.54
White male						
G_i^* statistic	0.12 (−0.11, 0.35)	0.31	0.05 (−0.23, 0.33)	0.74	0.09 (−0.19, 0.36)	0.54
Neighborhood poverty			−0.19 (−0.70, 0.33)	0.47	−0.27 (−0.79, 0.25)	0.31

Model adjustments:

Model 1 = *G*-statistic + *G*-statistic*Gender + Gender + Age + Age^2 + foreign born (Hispanic only) + Years in neighborhood + Site

Model 2 = Model 1 + neighborhood poverty

Model 3 = Model 2 + Education + Household income per capita + Wealth index + Working status + Marital status + Cancer + smoking status + language (Hispanic only) + foreign born (Hispanic only)

Notes: Estimates for the G_i^* statistic reflect at 1.96 unit change. Estimates for neighborhood poverty reflect a 1 standard deviation change. *p*-values reflect two-sided tests

G_i^* statistic is linked to 0.22 kg/m^2 higher BMI (Table 3: Model 1). Adjusting for neighborhood poverty and individual characteristics did not result in sizable changes in the segregation estimates. For black males, a consistently positive association was also found, though estimates were imprecise and included the null. Conversely, there was some evidence to suggest that Hispanic segregation is associated with lower BMI. In models controlling for neighborhood poverty, a 1.96 increase in the G_i^* is associated with a 0.17 and 0.20 kg/m^2 lower BMI for Hispanic females and males, respectively. However, adjusting for individual-level socioeconomic characteristics decreased the precision of estimates such that they were no longer significant. No association between segregation and BMI was found for either white females or males.

Neighborhood poverty was positively associated with BMI for Hispanic females, although only marginally so. For other races and males, poverty was not found to be significantly associated with BMI, net of racial/ethnic segregation. The relative stability of point estimates across Models 1 and 2 suggests that segregation–BMI link operates through pathways independent of neighborhood poverty.

Discussion

This study examined the cross-sectional and longitudinal associations between neighborhood-level racial/ethnic segregation and BMI, and assessed whether neighborhood poverty explained that association.

Results from the cross-sectional and longitudinal analyses indicated different patterning of the segregation–BMI relationship by race/ethnicity and gender. Cross-sectional results suggested that higher segregation is associated with lower BMI for white females but higher BMI for Hispanic females. No association was found for other racial/ethnic–gender groups. Our results, which indicate a deleterious association for Hispanics and no association for blacks, add to the mixed evidence from current cross-sectional studies [8–12, 14, 15]. In contrast, the longitudinal fixed-effect models found no association for either white females or

Table 3 Longitudinal Fixed-effect Model estimates of the associations of segregation or poverty with BMI by race/ethnicity: Multi-Ethnic Study of Atherosclerosis, 2000–2011

	Model 1		Model 2		Model 3	
	Estimate (95% CI)	*p*-value	Estimate (95% CI)	*p*-value	Estimate (95% CI)	*p*-value
Black female						
G_i^* statistic	0.22 (0.01, 0.44)	0.04	0.25 (0.04, 0.47)	0.02	0.24 (0.03, 0.46)	0.03
Neighborhood poverty			−0.12 (−0.33, 0.09)	0.25	−0.13 (−0.34, 0.08)	0.24
Black male						
G_i^* statistic	0.12 (−0.02, 0.26)	0.10	0.13 (−0.01, 0.28)	0.07	0.13 (−0.02, 0.28)	0.08
Neighborhood poverty			−0.11 (−0.29, 0.07)	0.25	−0.11 (−0.29, 0.06)	0.19
Hispanic female						
G_i^* statistic	−0.12 (−0.27, 0.03)	0.13	−0.17 (−0.33, −0.01)	0.04	−0.16 (−0.33, 0.00)	0.05
Neighborhood poverty			0.22 (0.00, 0.44)	0.05	0.22 (0.00, 0.44)	0.05
Hispanic male						
G_i^* statistic	−0.19 (−0.38, 0.00)	0.05	−0.20 (−0.39, −0.01)	0.04	−0.17 (−0.36, 0.02)	0.07
Neighborhood poverty			0.01 (−0.18, 0.21)	0.89	0.00 (−0.19, 0.20)	0.99
White female						
G_i^* statistic	0.01 (−0.24, 0.26)	0.93	−0.01 (−0.27, 0.25)	0.95	0.01 (−0.24, 0.27)	0.92
Neighborhood poverty			−0.05 (−0.30, 0.20)	0.71	−0.05 (−0.30, 0.20)	0.70
White male						
G_i^* statistic	−0.06 (−0.27, 0.15)	0.58	−0.09 (−0.31, 0.13)	0.41	−0.09 (−0.31, 0.13)	0.41
Neighborhood poverty			−0.09 (−0.27, 0.09)	0.33	−0.05 (−0.23, 0.13)	0.57

Model adjustments:

Model 1 = *G*-statistic + *G*-statistic*Gender + Years + Gender* Years + Baseline Age* Years + foreign born* Years (Hispanic only) + Baseline Years in neighborhood* Years

Model 2 = Model 2 + neighborhood poverty

Model 3 = Model 3 + Education* Years + Income per capita + Wealth index + Working status + Marital status + Cancer + smoking + language* Years (Hispanic only)

Notes: Estimates for the G_i^* statistic reflect at 1.96 unit change. Estimates for neighborhood poverty reflect a 1 standard deviation change. *p*-Values reflect two-sided tests

males, a positive association for black females—with a suggestive positive link for black males and a suggestive inverse association for both Hispanic females and males.

Results from the fixed-effect models are consistent with those found from a recent study that also used longitudinal data to examine the relationship between segregation and body weight. Applying a marginal structural modeling strategy, Pool et al. [36] found black women residing in highly segregated neighborhoods to be at a higher risk of being obese, compared to those residing in neighborhoods characterized by low segregation levels. Similar to our findings, they did not find evidence for an association between segregation and body weight for black men. (Pool et al. did not examine the impact of segregation on body weight for Hispanics or whites and we are not aware of any longitudinal study that has done so.) However, their marginal structural model point estimates were comparable to those from their conventional models, suggesting that there is little bias due to time-varying covariates being treated as confounders (versus simultaneous mediators) in conventional models. This is in contrast to our findings of large differences in our point estimates from the fixed-effect models compared to the cross-sectional models, which suggest that there might be significant bias due to unobserved confounding in the cross-sectional analysis. For example, white residents who reside in higher segregated neighborhoods may also tend to have higher proclivity to engage in healthy behaviors than whites living in less segregated areas. The attenuation of the salutary (inverse) associations to non-significance for white females in fixed-effect models is consistent with this scenario and suggests that the fixed-effect strategy was able to account for important factors, including health proclivity, that were not adjusted for in the cross-sectional models. In the case of Hispanics, individuals may prefer to reside in high Hispanic concentrated neighborhoods because of limited English proficiency and preference for co-ethnic networks. These factors may also be associated with barriers to health knowledge through limiting cross-cultural networks and dissemination of health-related information, suppressing the beneficial impacts of Hispanic segregation. The switch in direction of our point estimates between the fixed-effect and cross-sectional models suggests that cross-sectional analyses might underestimate the salutatory link for Hispanics.

The fixed-effect models, which automatically account for such time-invariant factors, demonstrated a 1.96 increase in the G^*statistic is associated with approximately a higher 0.24 kg/m^2 for black women and a suggestive 0.16 kg/m^2 lower BMI for Hispanic women. To provide some context, in fully adjusted models, unemployment was associated with a 0.15 kg/m^2 increase in BMI for blacks— though results were imprecise (95% CI = −0.19, 0.49). Hence, a 1.96 increase in the G^*statistic is associated with a comparable change in BMI as securing employment for Hispanic women and losing employment for black women. The deleterious association for blacks support the socio-economic stratification framework of segregation in which minority and disadvantaged groups in the US disproportionately bear the brunt of disorder and disease. Conversely, the direction of association for Hispanics is consistent with the healthy Hispanic enclave framework in which co-ethnic cohesion and salutary aspects of immigrant culture lead to better outcomes.

Consistent with other work, we did not find strong evidence, from either the cross-sectional or longitudinal models, to support the hypothesis that neighborhood poverty is the primary pathway through which segregation impacts body weight [11, 22]. The robustness of the segregation–BMI link after accounting for neighborhood poverty suggests that the mediating contextual mechanism(s) in the segregation–BMI pathway is not well captured by measures of poverty concentration.

Future studies should investigate other contextual features that may explain the link between segregation and bodyweight. For example, features of the built environment, such as urban sprawl and land use mix have been found to be consistently associated with weight status in North America [37]. Further, residing in ethnic enclaves, possibly due to higher availability of different ethnically oriented foods, have been found to be associated with healthier diets [14]. As such, examining more specific measures that capture the availability of culturally familiar foods that help to preserve native diets may provide more explanatory power. Protection against stressors from discrimination and acculturation, hypothesized protective aspects of Hispanic enclaves, may also play a role in explaining the relationship between segregation and BMI for Hispanics and warrant further investigation [16, 38].

Strengths and limitations

While our study was not able to explain the link between segregation and BMI for blacks and Hispanics, it represents a significant step towards understanding the relationship between racial/ethnic segregation and body weight. We used population-based data, clinically measured body-weight, and more appropriate measures of neighborhood-level segregation that can be used for cross-city comparisons. Further, to our knowledge, this study is the first to employ a fixed-effect strategy in examining the relationship between local racial/ethnic segregation and body weight. The unique strength of the fixed-effect approach is that the analytical strategy accounts for all time-invariant confounding without those factors having to be explicitly included in the model, resulting in estimates that are more robust to unobserved confounding—a ubiquitous threat to causal inference in conventional cross-sectional models.

However, this study is not without limitations. First, fixed-effect models cannot account for unmeasured time-varying factors. For example, if changes in individuals' neighborhood segregation levels also correspond to unobserved changes in health behavior choices that influences body weight, fixed-effect estimates are still susceptible to omitted variable bias. In additional analyses, we added diet and physical activity as time-varying covariates and inferences remained the same (results not shown).

Second, while the fixed-effect methodology offers the advantage of accounting for all time-invariant confounding, it does so by relying on the intra (within)-person variation to generate estimates. This may result in lower efficiency (wider confidence intervals), compared to random effects models, particularly if within-person characteristics do not change substantially across time. For example, though the stable segregation point estimates for Hispanics from Models 2 to 3 indicated there was little bias without inclusion of individual-level characteristics, it came at a cost of lower precision, which resulted in a loss of significance. In our full analytical sample for the fixed-effect models, the intra-person coefficient of variation for G^*stat, BMI, and neighborhood poverty are 0.56, 0.06, and 0.34, respectively. In contrast, the inter-person variations were approximately two to three times greater.

Lastly, though MESA's sample is multi-ethnic and geographically diverse, it is based on a small number of cities and does not include those who were diagnosed with cardio-vascular disease at baseline. Hence, results may not be generalizable to the general population.

Conclusion

Results indicate that racial/ethnic segregation can be associated with both higher and lower levels of BMI. This suggests that the impact of segregation might not always be detrimental, with possible salutary impacts under certain circumstances. What those circumstances might be require further investigation. However, the persistence of these associations after accounting for neighborhood poverty implies that the segregation–BMI link may operate through pathways that are not readily captured by neighborhood poverty levels. Investigations into the cultural, social, and environmental aspects of racial/ethnic isolation that are less correlated with concentration of poverty, and how these characteristics vary by race/ethnicity, may help provide a better understanding of how segregation influences body weight.

Code availability

SAS code to produce Tables 1–3 is available upon request.

Funding This research was supported by contracts N01-HC-95159, N01-HC-95160, N01-HC-95161, N01-HC-95162, N01-HC-95163, N01-HC-95164, N01-HC-95165, N01-HC-95166, N01-HC-95167, N01-HC-95168, and N01-HC-95169 from the National Heart, Lung, and Blood Institute, by grants UL1-TR-000040 and UL1-TR-001079 from NCRR, by grant R01 HL071759 from National Heart, Lung, and Blood Institute at the National Institutes of Health, and by grant P60 MD002249 from National Institute of Minority Health and Health Disparities. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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