Relationship of Racial Residential Segregation to Newly Diagnosed Cases of HIV among Black Heterosexuals in US Metropolitan Areas, 2008–2015

Umedjon Ibragimov · Stephanie Beane · Adaora A. Adimora · Samuel R. Friedman · Leslie Williams · Barbara Tempalski · Ron Stall · Gina Wingood · H. Irene Hall · Anna Satcher Johnson · Hannah L. F. Cooper

Published online: 4 September 2018

Abstract Social science and public health literature has framed residential segregation as a potent structural determinant of the higher HIV burden among black heterosexuals, but empirical evidence has been limited. The purpose of this study is to test, for the first time, the association between racial segregation and newly diagnosed heterosexually acquired HIV cases among black adults and adolescents in 95 large US metropolitan statistical areas (MSAs) in 2008–2015. We operationalized racial segregation (the main exposure) using Massey and Denton's isolation index for black residents; the outcome was the rate of newly diagnosed HIV cases per 10,000 black adult heterosexuals. We tested the relationship of segregation to this outcome using multilevel multivariate models of longitudinal (2008–2015) MSA-level data, controlling for potential confounders and time. All covariates were lagged by 1 year and centered on baseline values. We preliminarily explored mediation of the focal relationship by inequalities in education, employment, and poverty rates. Segregation was positively associated with the outcome: a one standard deviation decrease in baseline isolation was associated with a 16.2% reduction

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11524-018-0303-1) contains supplementary material, which is available to authorized users.

U. Ibragimov (✉) · S. Beane · H. L. F. Cooper
Department of Behavioral Sciences and Health Education, Rollins School of Public Health, Emory University, Atlanta, GA, USA
e-mail: mail.umed@yahoo.com

A. A. Adimora
Division of Infectious Diseases, School of Medicine, and Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, NC, USA

S. R. Friedman · L. Williams · B. Tempalski
National Development and Research Institutes Inc, New York, NY, USA

R. Stall
Department of Behavioral and Community Health Sciences and Department of Infectious Diseases and Microbiology, Graduate School of Public Health, University of Pittsburgh, Pittsburgh, PA, USA

G. Wingood
Department of Sociomedical Sciences, Lerner Center for Public Health Promotion, Mailman School of Public Health, Columbia University, New York, NY, USA

H. I. Hall · A. S. Johnson
HIV Incidence and Case Surveillance Branch, Centers for Disease Control and Prevention, Atlanta, GA, USA

in the rate of new HIV diagnoses; one standard deviation reduction in isolation over time was associated with 4.6% decrease in the outcome. Exploratory mediation analyses suggest that black/white socioeconomic inequality may mediate the relationship between segregation and HIV. Our study suggests that residential segregation may be a distal determinant of HIV among black heterosexuals. The findings further emphasize the need to address segregation as part of a comprehensive strategy to reduce racial inequities in HIV.

Keywords HIV/AIDS · Racial segregation · Health disparity

Introduction

Though estimated HIV incidence is declining in the USA [1], the new rate of HIV diagnoses is still disproportionately higher for black adults and adolescents [2]. According to the Centers of Disease Control and Prevention (CDC), the rate of new HIV diagnoses among this population in 2016 was 43.6 per 100,000, as compared to 17.0/100,000 among Hispanic/Latinos, 5.2/100,000 among the white population, and 5.5/100,000 among Asians [2]. This disparity is especially striking among heterosexuals; while black adults and adolescents constitute about 13% of the US population [3], they accounted for approximately 63% of persons diagnosed in 2016 with infection attributed to heterosexual contact (for reference, this percentage was 38.1% of male-to-male sexual transmission cases and 35.4% of transmission via injection cases) [2].

Structural Racism and Health

Structural racism can be defined as racial discrimination emerging "…via mutually reinforcing systems of discrimination (e.g., in housing, education, employment, earnings, benefits, credit, media, health care, criminal justice, etc.) that in turn reinforce discriminatory beliefs, values, and distribution of resources" [4, p. 650]. Social science and public health have emphasized structural racism as a fundamental cause of negative health outcomes, including disproportionately high vulnerability to HIV infection, among black adults and adolescents [5–8]. Black/white residential segregation is one of the most prominent manifestations of structural racism in the USA [9]. Facilitated by racial prejudice and maintained by numerous discriminatory federal and local housing policies as well as lending and real estate industry practices, racial/ethnic segregation remained high throughout the twentieth century despite expansions of black civil rights [10, 11]. Although segregation has declined overall since 1990, many US metropolitan areas remain highly segregated. In 2010 for example, the mean black isolation index (a measure of segregation) was 45.2, indicating that on average, a black person lived in a census tract where 45.2% of residents were also black [12]. In the twenty-first century, persistent segregation is sustained by a range of factors including discriminatory housing practices, limited resources (e.g., school quality and housing values) and greater hazards (crime, exposure to legal and illegal substances and to police, and thus incarceration or violence) in predominately black neighborhoods, and the inherent difficulty of overcoming historically high segregation rates [10, 12–14].

Residential Segregation and HIV

Literature on health disparities often invokes segregation as a cause of the higher burden of HIV [6, 15–19] and traces several pathways to explain this relationship. Segregation sorts black and white households into separate and unequal neighborhoods, with black families disproportionately likely to live in neighborhoods with multiple hazards and fewer resources [20, 21]. For example, segregation may trigger and concentrate violent crime [10, 21], which, coupled with a criminal justice system that disproportionately arrests and incarcerates black people [7, 22], leads to higher incarceration rates among black men [23]. High incarceration of men, in turn, skews sex ratios in predominately black neighborhoods [24]. In such neighborhoods, black heterosexual women have to choose from a smaller pool of available sexual partners and more often than white women, establish sexual relationships with men who are at higher risk of HIV [19]. Socioeconomic disadvantage created by segregation may also contribute to HIV risk for heterosexual residents via a combination of injecting drug use [8] and transactional sex [25] in predominately black neighborhoods. Segregation may disrupt the participation of black residents in the HIV continuum of care by limiting geographic access to health

care locally and by limiting access to transportation to services that are farther away [26, 27].

Segregation and associated socioeconomic inequities across racial groups were even more prominent four decades ago [10], at the dawn of the HIV epidemic in the USA, which may explain the historically high HIV prevalence in the black population. High background HIV prevalence may expose black residents to increased risk of HIV via the racially homogenous sexual networks that segregated areas can foster [15]. Segregation varies substantially across metropolitan statistical areas (MSAs) and, to some extent, time [12], and so, segregation may explain not only black/white inequities in health, but also *within*-group variations in health among black adults and adolescents living in different MSAs.

Several area-level studies have reported empirical associations between residential segregation (measured as black isolation or black-white dissimilarity) and rates of HIV-related outcomes, including HIV incidence (all transmission modes) among black adults (in cities) [6], the prevalence of HIV in the general population (in counties) [5], and the rate of AIDS incidence among heterosexuals (in MSAs) [28]. However, methodological limitations of these studies might have affected their internal validity. For example, Henderson [5] used HIV prevalence as the outcome, but variations in HIV prevalence are difficult to interpret in the era of modern antiretroviral therapy (e.g., longer survival among people living with HIV); Buot et al.'s [6] analysis was bivariate, potentially excluding key confounders; both Henderson and Buot et al. use cross-sectional design. Further, none of these studies focused specifically on the relationship between segregation and heterosexually acquired HIV cases.

Study Rationale

The social science and public health literature has posited that segregation is a potent structural determinant of the higher burden of heterosexually acquired HIV among black adults, but empirical data on this relationship is weak. The present study addresses this crucial empirical deficit. Specifically, we use multilevel, multivariable methods to test the hypothesis that MSAs that are more racially/ethnically segregated (measured as black isolation) will have higher rates of newly diagnosed HIV cases among black heterosexual adults and adolescents.

Methods

We used hierarchical linear modeling (HLM) methods to assess the relationship between residential isolation and HIV diagnosis rates among heterosexual black adults (here and below, we refer to non-Hispanic black individuals as "black" and to non-Hispanic white individuals as "white") living in a cohort (2008–2015) of MSAs. The unit of analysis was the MSA. This analysis is part of a larger longitudinal study spanning 1992–2015, so we used 1992 MSA boundaries. The MSA cohort was a census of all MSAs in the contiguous United States and Puerto Rico with population sizes of 500,000 or greater in 1992 ($n = 96$). However, one MSA (Puerto Rico) did not report population data for non-Hispanic black residents, which reduced our dataset for analysis ($n = 95$).

Measures

Supplemental Table S1 details the data type and source for each measure.

Outcome

For each MSA and year, we calculated rates of newly diagnosed cases of HIV among black heterosexuals as the number of new HIV diagnoses among black people aged 15–64 attributed to heterosexual contact per 10,000 black residents aged 15 to 64 years:

$$\frac{\text{No.of new HIV diagnoses among black adults and adolescents attributed to heterosexual contact}_{\text{YeariMSAj}}}{\text{No.residents aged 15–64 years who are black}_{\text{YeariMSAj}}} \times 10,000 \quad (1)$$

Data on new diagnoses of heterosexually acquired HIV were received from CDC for each year, by race/ethnicity. These data were available for 2008 to 2015. Population data by race/ethnicity for people aged 15–64 were obtained from US Census Bureau's Intercensal Population Estimates Program.

Independent variables

The main exposure of interest—residential segregation of black residents—was operationalized as the black isolation index [29]. Isolation is a measure of residential exposure, one of Massey and Denton's [29] five residential segregation dimensions, and is a useful dimension for infectious disease epidemiology because it measures potential contact within a group [30]. For our study, the isolation index measures the probability that non-Hispanic black adults will come into contact with others of the same race/ethnicity. This measure was obtained from US Census and the American Community Survey for years 2000, 2010, and 2014 respectively. Following Massey and Denton, the equation used to calculate the isolation index is:

$$\sum_{i=1}^{n}\left[\left(\frac{\text{Total number of black residents in census tract}}{\text{Total number of black residents in the MSA}}\right)\left(\frac{\text{Total number of black residents in census tract}}{\text{Total population in census tract}}\right)\right] \quad (2)$$

We used linear interpolation to calculate values for intercensal years for residential isolation (and for all other covariates derived from the decennial census).

Based on past research of segregation as a predictor of HIV and other STIs [5, 31, 32], we considered several facets of MSA-level demographic composition as potential confounders: total MSA population size, percentage of MSA population younger than 29 (for all races and for black adults separately), and population and housing densities per square mile. We posit that these demographic characteristics and residential isolation may have common unobserved antecedents (e.g., migration patterns) that may also influence HIV rates; we also assume that these characteristics are not likely to be affected by segregation, i.e., they are not mediators. At the same time, we did not account for the effect of known HIV predictors (e.g., socioeconomic and criminal justice characteristics, prevalence of men who have sex with men [MSM] or people who inject drugs [PWID], HIV prevalence among these groups, and access to services) that may be affected by segregation to avoid controlling for potential mediators.

We also preliminarily explored if selected socioeconomic and demographic factors might mediate the relationship between black segregation and rates of new HIV diagnoses, as suggested by Buot et al.'s model of HIV ecology. Buot et al. posited that in the mature HIV epidemic (such as the one in the USA), segregation, lack of economic opportunities and income inequality between top and bottom earners act as interrelated distal determinants of HIV risk affecting sexual networks, concurrency patterns, and individual risky behaviors via a constellation of intermediary factors (incarceration, destabilized marriages, imbalanced sex ratios, etc.) [6]. Specifically, we assessed the percentage among black residents of each of the following characteristics, as well as black/white inequalities (adjusted by each population size) in each of these characteristics: population employed in civilian labor force, population living at or below the federal poverty level, and adults aged 25 or older with no high school diploma or equivalent. The sex ratio for black adults (i.e., ratio of adult males to adult females) dichotomized as equitable (0.95–1.05) vs. inequitable (outside of this range) was also assessed as a possible mediator [19]. Finally, we measured MSA-level annual rates of new HIV diagnoses per 10,000 white residents aged 15–64 obtained from the CDC as a potential mediator.

Analysis

We used descriptive statistics to summarize the central tendency and dispersion of each variable. We built models using a 3-stage process: first, modeling temporal changes in the outcome and then conducting bivariate and multivariable analyses. We excluded observations with missing data (less than 2% of total observations)

from the analysis. We conducted our analysis in SAS 9.4 (SAS Institute Inc., Cary, NC).

Stage 1: modeling change in the outcome over time

We used a log transformation to normalize the distribution of HIV diagnosis rates and to linearize the relationship between residential isolation and this outcome. All models (stages 1–3) accounted for clustering of annual observations within MSAs and of MSAs within the states. Nested models yielded the smallest Akaike information criterion (AIC) when time since baseline was modeled as quadratic. Therefore, we modeled time as quadratic in bivariate and multivariable models. We assessed the covariance parameters and calculated intraclass correlation coefficients (ICCs) and reduction in the residual outcome variance between unconditional means and growth models (pseudo R^2) to assess the variability of the outcome within and between MSAs and states and its association with time [33].

Stage 2: bivariate models

Time-varying correlates were centered at their baseline values to aid interpretation. Specifically, we created variable dyads, with one variable for the baseline value of the variable and the other capturing yearly change in the variable since baseline. For the dichotomous sex ratio variable, change over time was operationalized as an interaction term with the centered time. All covariates and the outcome were standardized by creating z scores, and we report standardized coefficients for bivariate and multivariate models. We created 1-, 2-, and 3-year lags between the exposure of interest (isolation) and the outcome to account for the time needed for the exposure to produce the outcome and examined correlations between the lagged exposure and the outcome. There was no difference in the absolute magnitudes of the relationship across models with isolation lagged by 1, 2, and 3 years, so we selected a 1-year lag.

To select potential confounders for the final model, we tested associations of 1-year lagged covariate dyads with the outcome in bivariate hierarchical linear models (HLMs; *NB*, each bivariate model included time). Since our MSA cohort was a census of MSAs with a population of 500,000 or greater, and not a sample, assumptions associated with interpretation of p values and confidence intervals do not hold [34, 35]. Therefore, we focus on the *magnitude* of association, instead of p values, to determine substantive significance and decide which covariates to include in the final model; we report confidence intervals as a heuristic guide. To evaluate the magnitude of association, we summed the absolute value of each dyad's standardized coefficient. Based on literature on effect size interpretation and previous research, we a priori selected a cut point of 0.20 as a recommended minimum effect size of practical significance [36], and when the magnitude of association in the bivariate model for a dyad was $\geq |0.20|$, we included that dyad in the final model [37]. To assess whether potential mediator dyads should be analyzed in our exploratory mediation analyses, we also used this method with the lower cutoff value of $> |0.10|$ reflecting the exploratory nature of this analysis. Possible mediators were also 1-year lagged, except for the rates of HIV diagnoses among white adults, for which we lacked 2007 data.

Stage 3: multivariable analysis

The final HLM included all covariates that met the bivariate model cut point for inclusion in the final multivariable model.

To inform future research, we preliminarily explored possible mediators of the association between segregation and the outcome. Each mediator was added to the model one at a time to avoid simultaneous testing of mediators that may be part of the same causal pathway. Specifically, we ran seven models, one for each possible mediator. We compared the magnitudes of the effect estimate for black isolation across our final model and each mediator model to identify possible mediators; a priori, we set a cut point of $\geq |10\%|$ difference between the effect estimate for the isolation index across unmediated and mediated models as indicating possible mediation.

Since we log transformed the outcome to normalize the relationship with covariates, we used back transformation [38] to report percent change in new HIV diagnoses per 10,000 for a one standard deviation (SD) change in the exposure variable to aid interpretation.

Results

The median rate of newly diagnosed cases of HIV among black heterosexuals was 2.45 per 10,000 adults in 2008 (25th and 75th percentiles: 1.60/10,000, 4.00/

Table 1 Rates of newly diagnosed cases of HIV acquired through heterosexual contact among black adults (aged 15–64 years) per 10,000 over time, and possible structural independent variables: 95 large US metropolitan statistical areas, 2008–2015.

	Mean	Std dev	Median	25th Pctl	75th Pctl
Newly diagnosed HIV cases per 10,000 black heterosexual adults[a]					
Baseline (2008)	3.19	2.56	2.45	1.60	4.00
Change between 2008 and 2015	−1.18	1.75	−0.92	−1.89	−0.21
Correlates					
Black residential isolation index					
Lagged baseline (2007)	35.37	18.97	36.56	17.53	48.85
Change between 2007 and 2014	−2.40	1.79	−2.27	−3.66	−1.08
Total population size of MSA (thousands)					
Lagged baseline (2007)	1971.91	1786.10	1383.70	833.08	2289.07
Change between 2007 and 2014	138.89	162.17	70.92	40.21	198.93
% of population ages 15–29, all races					
Lagged baseline (2007)	21.08	1.79	21.05	20.14	22.00
Change between 2007 and 2014	−0.42	0.68	−0.45	−0.80	−0.08
% of black residents of ages 15–29					
Lagged baseline (2007)	24.43	1.93	24.17	23.30	25.34
Change between 2007 and 2014	−0.17	0.82	−0.17	−0.76	0.27
Population density per square mile					
Lagged baseline (2007)	945.97	1641.31	538.62	354.42	967.78
Change between 2007 and 2014	47.58	58.46	35.42	17.06	64.95
Housing density per square mile					
Lagged baseline (2007)	383.56	669.52	231.40	147.91	396.24
Change between 2007 and 2014	28.97	51.32	20.70	10.94	33.40
Possible mediators					
Newly diagnosed HIV cases per 10,000 white heterosexual adults[a]					
Baseline (2008)	0.17	0.14	0.14	0.08	0.21
Change between 2008 and 2015	−0.04	0.10	−0.03	−0.07	0.02
Male to female ratio, black adults[a]					
Lagged baseline (2007)	0.96	0.22	0.88	0.84	1.00
Change between 2007 and 2014	0.00	0.07	0.01	0.00	0.02
MSAs with equitable sex ratio of black adults[a]					
Lagged baseline (2007), % (*n*)	15.79 (15)				
Lagged endline (2014), % (*n*)	20.00 (19)				
Percentage of non-Hispanic black adults[a] (25 and up) without a high school diploma or equivalent					
Lagged baseline (2007)	17.01	4.73	17.04	14.14	19.90
Change between 2007 and 2014	−3.51	1.71	−3.74	−4.81	−2.37
Ratio[b] of black to white adults[a] without a high school diploma or equivalent, adjusted for population size					
Lagged baseline (2007)	1.97	0.62	1.90	1.59	2.24
Change between 2007 and 2014	0.14	0.25	0.08	−0.01	0.26
Percentage of black employed adults[a]					
Lagged baseline (2007)	60.56	6.01	61.74	57.32	64.56
Change between 2007 and 2014	−0.19	2.34	0.02	−1.77	1.35
Ratio[b] of white to black employed adults[a], adjusted by population size					
Lagged baseline (2007)	1.02	0.10	1.01	0.97	1.07
Change between 2007 and 2014	−0.02	0.04	−0.02	−0.05	0.00

Table 1 (continued)

	Mean	Std dev	Median	25th Pctl	75th Pctl
Percentage of black residents with income[c] below poverty level					
Lagged baseline (2007)	20.75	6.74	20.84	16.06	25.37
Change between 2007 and 2014	1.00	2.64	1.04	−0.25	2.23
Ratio[b] of black to white residents with income[c] below poverty level, adjusted by population size					
Lagged baseline (2007)	2.65	0.71	2.58	2.28	3.00
Change between 2007 and 2014	−0.23	0.30	−0.21	−0.38	−0.08

2008 to 2015 is the timeframe for the outcome. Correlates were lagged 1 year and reflect 2007–2014

Note: Correlates were lagged 1 year because we did not expect a change in the correlates to have an instantaneous effect on the outcome

[a] For this study, adults are defined as persons aged 15–64. For those without a high school diploma or equivalent, the census reports these data for those ages 25–64 to allow time for non-diploma holders to obtain an equivalent. Yearly sex ratios by race were only available from census intercensal estimates, which report the age range 18–64

[b] Ratios adjusted for population size are ratios of percentages out of the relevant population

[c] Income refers to individual income

10,000); this rate decreased by 37.5% to 1.53 per 10,000 adults in 2015 (25th and 75th percentiles for change: − 1.89/10,000, − 0.21/10,000) (Table 1). Analysis of the ICC suggested that a meaningful proportion of the outcome variance was attributable to differences *between* MSAs (27.5%) and *between* states (35.3%), thus justifying multilevel analysis. Comparison of unconditional means and growth models in HLM indicated that 24% of the outcome variation within MSAs was associated with linear and quadratic time (pseudo $R^2 = 0.24$).

The median black isolation index was 36.6% in 2007 (25th and 75th percentiles: 17.5, 48.9). This means that in half of these MSAs, on average black residents lived in a census tract where more than a third of the residents were also black. This index remained fundamentally constant over the subsequent 8 years (2015 median: 34.3%; 25th and 75th percentiles for change: − 3.7, − 1.1).

The median population size as well as the densities of population and housing in MSAs slightly increased, while the median percentage of young people remained essentially stable. In 2007, the median male to female sex ratio for black adults was 0.88 (i.e., 88 men for every 100 women), and the 75th percentile was 1.00, indicating relative deficit of black men in most MSAs that year. In 2007, the vast majority of MSAs had an inequitable sex ratio for black adults (84.2%, $n = 80$); this proportion was constant across time. Socioeconomic indicators revealed relatively high levels of inequality between white and black adults in high school graduation and poverty rates that changed little over time (Table 1).

The rate of new HIV diagnoses among white heterosexuals was 0.14 per 10,000 adults in 2008, or almost 17.5 times as low as that of black heterosexuals; by 2015, this disparity between black vs. white new HIV diagnosis rates had slightly decreased to 14 (Table 1).

Bivariate analyses found that baseline isolation was positively correlated with the outcome ($B =$ 0.31), while there was weak association between the linear change in isolation and the outcome ($B = 0.07$). Bivariate models indicated that only the total population size met the cut point ($\geq |0.20|$) for inclusion in the final multivariable model. Almost all potential mediators (except for white-black employment ratio) passed the test of strength of bivariate association ($\geq |0.10|$) with the outcome (Table 2).

The positive relationship between baseline black isolation and the outcome persisted in the multivariable model that controlled for MSA population size and time ($B = 0.23$, Table 2). According to this model, a 19% difference (i.e., one SD difference) in the baseline isolation variable was associated with a 16.2% difference in the rate of newly diagnosed cases of HIV in 2008–2015. *Change* in isolation over time demonstrated weak positive association with the outcome ($B = 0.07$, Table 2), which can be translated to 4.6% change in HIV rates per one SD difference in change in isolation over time. Population size dyad and time remained correlated with the outcome in the final model, although the magnitude of association for population size dyad was below |0.20| (Table 2).

Table 2 Possible structural correlates of log rates of newly diagnosed cases of HIV acquired through heterosexual contact among black adults (aged 15–64 years) per 10,000: 95 large US metropolitan statistical areas, 2008–2015.

Correlates	Bivariate model standardized coefficient (95% CI)	Multivariate model[a] standardized coefficient (95% CI)
Black residential isolation index		
Lagged baseline (2007)	0.31 (0.15, 0.46)	0.23 (0.07, 0.40)
Change between 2007 and 2014	0.07 (−0.02, 0.16)	0.07 (−0.02, 0.16)
Time		
Years since 2008	−0.20 (−0.27, −0.13)	−0.16 (−0.25, −0.07)
Years, squared (quadratic)	0.05 (0.00, 0.10)	0.05 (0.00, 0.10)
Potential confounders		
Total population size of MSA*		
Lagged baseline (2007)	0.20 (0.08, 0.33)	0.13 (0.00, 0.26)
Change between 2007 and 2014	0.00 (−0.10, 0.08)	0.00 (−0.08, 0.10)
% of population ages 15–29, all races		
Lagged baseline (2007)	− 0.03 (−0.17, 0.11)	–
Change between 2007 and 2014	0.00 (−0.08, 0.08)	–
% of black residents of ages 15–29		
Lagged baseline (2007)	−0.11 (−0.24, 0.01)	–
Change between 2007 and 2014	−0.07 (−0.14, 0.00)	–
Population density per square mile		
Lagged baseline (2007)	0.14 (0.01, 0.28)	–
Change between 2007 and 2014	0.00 (−0.09, 0.09)	–
Housing density per square mile		
Lagged baseline (2007)	0.15 (0.01, 0.28)	–
Change between 2007 and 2014	0.00 (−0.09, 0.08)	–

Timeframe for the outcome, black heterosexually acquired HIV, is 2008 to 2015. The timeframe for correlates is lagged 1 year, 2007–2014, because we did not expect an instantaneous effect on the outcome

CI, confidence interval

[a] The multivariate model includes covariates indicated by * (meeting substantive significance cut point) and states as a categorical independent variable (parameters for states not shown here)

Preliminary exploration of possible mediators demonstrated that adding rates of white HIV diagnoses, high school drop out for black adults, and white-black inequalities in rates of drop out and poverty to the final model changed the magnitude of association between the baseline exposure (isolation) and the outcome (new HIV diagnoses) above the predetermined cut point (≥|10%|, Table 3). We observed the largest change in the focal association when we added white HIV diagnosis rate and the percentage of black adults with no high school diploma to the model (34.8 and 51.4% decrease, correspondingly). Adding equitable sex ratio for black adults to the final model did not attenuate the focal relationship. Since the final model yielded low standardized coefficient for change in isolation over time, the relative change in the strength of association between this exposure variable and the outcome was artificially high when most of the potential mediators were added, so we do not report related findings.

Discussion

Past literature has consistently posited that racial segregation may be a fundamental cause of HIV among black adults [15, 39]; however, empirical evidence to support this hypothesis has been limited. To our knowledge, our study is the first longitudinal test of the association between residential segregation and rates of new HIV diagnoses among black heterosexual adults in large

Table 3 Exploratory testing of select mediators of the relationship between black residential isolation and the log rate of new HIV cases: 95 large US metropolitan statistical areas, 2008–2015.

Independent variables[a]	Standardized coefficient for bivariate model (95% CI)	Standardized coefficient for multivariate model (95% CI)	% change[f] in standardized coefficient for the focal exposure[g]
Newly diagnosed HIV cases per 10,000 white heterosexual adults[b]			
Baseline (2008)	0.41 (0.27, 0.56)	0.34 (0.20, 0.48)	−34.75
Change between 2008 and 2015	0.05 (−0.02, 0.12)	0.05 (−0.02, 0.12)	*
Equitable male to female ratio, black adults[b]			
Lagged baseline (2007)	−0.23 (−0.57, 0.11)	−0.06 (−0.39, 0.28)	5.08
Change between 2007 and 2014 (interaction of the variable with time)	0.04 (−0.01, 0.09)	0.03 (−0.02, 0.08)	*
Percentage of non-Hispanic black adults[b] (25 and up) without a high school diploma or equivalent			
Lagged baseline (2007)	0.25 (0.11, 0.40)	0.25 (0.11, 0.39)	−51.35
Change between 2007 and 2014	0.01 (−0.08, 0.11)	0.00 (−0.10, 0.04)	*
Ratio[c] of black to white adults[b] without a high school diploma or equivalent, adjusted for population size			
Lagged baseline (2007)	0.24 (0.12, 0.35)	0.22 (0.12, 0.33)	−15.48
Change between 2007 and 2014	−0.01 (−0.08, 0.06)	−0.02 (−0.09, 0.05)	*
Percentage of black employed adults[b]			
Lagged baseline (2007)	0.14 (0.005, 0.27)	0.09 (−0.03, 0.22)	3.96
Change between 2007 and 2014	0.02 (−0.06, 0.09)	0.02 (−0.06, 0.10)	*
Ratio[c] of white to black employed adults[b], adjusted by population size[d]			
Lagged baseline (2007)	−0.03 (−0.18, 0.11)	–	–
Change between 2007 and 2014	−0.02 (−0.09, 0.05)	–	–
Percentage of black residents with income[e] below poverty level			
Lagged baseline (2007)	−0.06 (−0.21, 0.08)	−0.04 (−0.17, 0.10)	2.71
Change between 2007 and 2014	0.06 (−0.01, 0.12)	0.06 (−0.01, 0.12)	*
Ratio[c] of black to white residents with income[e] below poverty level, adjusted by population size			
Lagged baseline (2007)	0.16 (0.02, 0.30)	0.12 (−0.02, 0.26)	−22.58
Change between 2007 and 2014	0.06 (−0.01, 0.12)	0.06 (−0.01, 0.12)	*

2008 to 2015 is the timeframe for the outcome. Except for newly diagnosed HIV cases per 10,000 white heterosexual adults, correlates were lagged 1 year and reflect 2007–2014

Note: Correlates were lagged 1 year because we did not expect a change in the correlates to have an instantaneous effect on the outcome

*Due to the low absolute value of isolation change coefficient in the model without mediators, the relative change in this parameter is artificially high, so we do not report these findings

CI, confidence interval

[a] Each independent variable was added to the model one at a time

[b] For this study, adults are defined as persons aged 15–64. For those without a high school diploma or equivalent, the census reports these data for those ages 25–64 to allow time for non-diploma holders to obtain an equivalent. Yearly sex ratios by race were only available from census intercensal estimates which report the age range 18–64

[c] Ratios adjusted for population size are ratios of percentages out of the relevant population

[d] This variable was not tested as a mediator in the multivariate models due to weak bivariate associations with the outcome

[e] Income refers to individual income

[f] Compared to the standardized coefficients of the focal exposure (baseline isolation and change) for the final model without mediators (see Table 2)

[g] The focal exposure is black isolation in the metro area

MSAs in the USA. We found that the rate of new HIV diagnoses in MSAs varies across both MSAs and time, and that the black/white HIV inequity, although declining, still persists. Importantly, study results show that baseline residential isolation index and the rate of new HIV diagnoses are independently and positively associated.

Our findings support past area-level studies that also found a positive relationship between racial segregation and HIV-related outcomes among heterosexual residents, as well as PWID and MSM [5–7, 28]. By employing more rigorous methods (i.e., longitudinal design and name-based HIV diagnoses data), we strengthen the argument that structural racism, specifically residential segregation, is a fundamental determinant of HIV for black heterosexual populations. The relatively high magnitude of the association between baseline isolation and HIV (i.e., one SD change in baseline isolation corresponds to 16.2% change in HIV rates) emphasizes the potential effectiveness of addressing segregation as an HIV prevention strategy. We did not, however, find a substantial association between *change* in black isolation level and HIV. One explanation may be that changes in segregation during our relatively short study period were too small in magnitude to account for changes in the outcome. Additionally, our segregation measure also assumed that linear interpolation accurately reflects the actual change in isolation index during this period, which may be incorrect.

Determining if the association between segregation and HIV is causal rests, in part, on identifying plausible causal pathways linking these phenomena. The literature has posited that segregation may affect HIV rates among black heterosexuals via various mechanisms operating at community, network, and individual levels, including socioeconomic forces [8, 10, 20, 25, 40]. Our preliminary findings that white-black inequality in rates of poverty may play mediating roles while *absolute* poverty rates for black adults might not, highlight the role of the racialized socioeconomic systems in engendering HIV vulnerability. Other authors have also emphasized the role of racial economic inequality as an HIV risk factor, though cautioned that it does not fully explain racial inequities in HIV [41, 42]. Our models suggest that black employment level and black/white inequalities in employment do not mediate the relationship between segregation and HIV. This may be because the census measure of employment is suboptimal, since it does not differentiate between part-time, minimum wage job and full-time, salaried, high wage job [43]. Black adults are more likely to work in the former jobs than their white counterparts [44–46]. The preliminary finding that black educational attainment may mediate the association between segregation and HIV is aligned with past studies showing higher HIV rates for black residents in areas with lower graduation rates [6].

We had posited that imbalanced sex ratios might mediate the relationship between segregation and HIV because, according to past literature, (1) segregation may facilitate factors (e.g., high violent crime and racialized policing) [7, 10, 21] known to skew sex ratios of black adults [15, 19, 41], and (2) lower sex ratios are associated with higher HIV rates [5]. However, we found no evidence supporting this hypothesis. It is possible that our hypothesized cause-effect chain is incorrect, e.g., higher incarceration driven by segregation may affect HIV rates not via imbalanced sex ratios, but through destabilizing social and sexual networks [19]. Alternatively, enumeration errors (e.g., undercounting black men) in sex ratio measures may attenuate its relationship with HIV rates [19].

Our preliminary mediation analysis suggested that rates of HIV diagnosis among white heterosexuals may mediate the relationship between segregation and HIV diagnosis rates among black heterosexuals. This seems counter-intuitive: one would expect that segregated MSAs offer less opportunity for black and white heterosexuals to interact. An alternative explanation may be that white and black HIV diagnosis rates are correlated since both are influenced by the overall HIV incidence and prevalence rates in the MSA, and/or by ease of access to HIV testing, which may depend on segregation.

Our study has several strengths. Its longitudinal design allowed us to assess the directionality and temporality of associations. Data on the outcome were derived from name-based reporting, ensuring a more accurate measure of HIV than prevalence or incidence estimates used in other studies. Name-based reporting reduces duplication in HIV reporting when the same person living with HIV is tested several times; it reduces the problem of potential confounding, an important attribute because racial/ethnic segregation may correlate with the rates of duplicate HIV reporting. Operationalizing segregation within MSAs is aligned with its conceptualization as a function of central city/suburb interactions [47, 48].

Limitations include the relatively short time span for our analysis, driven by the recent (2008) initiation of name-based reporting across states, so we were unable to detect changes occurring over the longer period. The lack of data on isolation for intercensal years and use of linear interpolation to estimate isolation during those years might have led our models to inaccurately represent actual isolation trends. Our analysis covers the period of Great Recession and subsequent economic recovery, so the findings may be less generalizable to periods with different macroeconomic processes. Our results may have limited generalizability to smaller MSAs. Annual, MSA-specific data on HIV diagnoses were not available by race/ethnicity, mode of transmission and gender or age group, so we were unable to compare relationships between isolation and newly diagnosed cases of HIV across men and women or for different age groups. We were also unable to control for confounders operating within individuals, social networks, or geographic areas other than the MSA, or account for possible cross-population effects between PWID, MSM, and heterosexual residents or programs. Our mediation analysis was intended to be exploratory, and more rigorous analyses (e.g., structural equation modeling) are needed to refute or support existing theories about socioeconomic mechanisms.

Future research should address these limitations by combining MSA, neighborhood-level and individual-level analyses, including data on recent HIV diagnoses, accounting for the influence of HIV prevalence and relevant prevention and care programs in other key populations and applying advanced statistical methods (e.g., marginal structural modeling) to assess mediation and confounding.

Public Health Implications

This study provides further evidence about the harmful effects of segregation on health—this time, on new HIV diagnoses among black heterosexuals. Addressing some of the limitations of past studies, we strengthen the argument that racial segregation is a fundamental cause of HIV infection in the USA. Policy and community interventions promoting fair housing and socioeconomic equality should accompany evidence-based approaches to strengthen black residents' engagement in the HIV care continuum (e.g., intensive outreach, addressing unmet non-HIV needs, and peer patient navigation [49]). Eliminating this potent form of structural discrimination may also reduce the burden of multiple other adverse health outcomes among the black population.

Acknowledgments The following grants supported this project: Metropolitan Trajectories of HIV Epidemics, Drug Use, and Responses in US Key Populations (DA037568; PIs: Cooper, Friedman, and Stall); Center for AIDS Research at Emory University (P30AI050409; PI: Del Rio); and Center for Drug Use and HIV Research (P30 DA11041; PI Sherry Deren).

We express our gratitude to the US Centers for Disease Control and Prevention for sharing the following databases: the HIV Counseling and Testing System database and the National HIV Surveillance System database.

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

References

1. Hall HI, Song R, Tang T, *et al.* HIV trends in the United States: diagnoses and estimated incidence. *JMIR Public Health and Surveillance.* 2017;3(1).
2. Centers for Disease Control and Prevention. *HIV surveillance report. Diagnoses of HIV infection in the United States and Dependent Areas*, Atlanta, GA;2016. 2017;28.
3. United States Census Bureau. QuickFacts. Population estimates, July 1, 2016. Available at: https://www.census.gov/quickfacts/fact/table/US/PST045216. Accessed September, 13, 2017.
4. Krieger N. Discrimination and health inequities. *Int J Health Serv.* 2014;44(4):643–710.
5. Henderson L. Mass incarceration, residential segregation and racial disparities in HIV. *J AIDS HIV Res*. 2016;8(11):150–62.
6. Buot ML, Docena JP, Ratemo BK, et al. Beyond race and place: distal sociological determinants of HIV disparities. *PLoS One*. 2014;9(4):e91711.
7. Friedman SR, Tempalski B, Brady JE, West BS, Pouget ER, Williams LD, et al. Income inequality, drug-related arrests, and the health of people who inject drugs: reflections on seventeen years of research. *Int J Drug Policy.* 2016;32:11–6.
8. Cooper HL, Friedman SR, Tempalski B, Friedman R. Residential segregation and injection drug use prevalence among black adults in US metropolitan areas. *Am J Public Health*. 2007;97(2):344–52.
9. Gee GC, Ford CL. Structural racism and health inequities: old issues, new directions. *Du Bois Rev-Soc Sci Res Race. Spr*. 2011;8(1):115–32.
10. Massey DS, Denton NA. *American apartheid: segregation and the making of the underclass*: Harvard University Press, Cambridge, MA; 1993.
11. Gotham KF. Urban space, restrictive covenants and the origins of racial residential segregation in a US city, 1900–50. *Int J Urban Reg Res*. 2000;24(3):616–33.

12. Logan JR, Stults BJ. The persistence of segregation in the metropolis: new findings from the 2010 census. *Census brief prepared for Project US2010.* 2011.
13. Dawkins CJ. Recent evidence on the continuing causes of black-white residential segregation. *J Urban Affairs*. 2004;26(3):379–400.
14. Drucker E. *A plague of prisons: the epidemiology of mass incarceration in America*: New Press, The, New York, NY; 2013.
15. Adimora AA, Schoenbach VJ, Floris-Moore MA. Ending the epidemic of heterosexual HIV transmission among African Americans. *Am J Prev Med*. 2009;37(5):468–71.
16. Adimora AA, Schoenbach VJ. Social context, sexual networks, and racial disparities in rates of sexually transmitted infections. *J Infect Dis*. 2005;191(Supplement_1):S115–22.
17. Adimora AA, Schoenbach VJ. Social determinants of sexual networks, partnership formation, and sexually transmitted infections. *The new public health and STD/HIV prevention*: Springer; 2013:13–31.
18. Hogben M, Leichliter JS. Social determinants and sexually transmitted disease disparities. *Sex Transm Dis*. 2008;35(12 Suppl):S13–8.
19. Pouget ER. Social determinants of adult sex ratios and racial/ethnic disparities in transmission of HIV and other sexually transmitted infections in the USA. *Phil Trans R Soc B*. 2017;372(1729):20160323.
20. Massey DS. Segregation and stratification: a biosocial perspective. *Du Bois Rev: Soc Sci Res Race*. 2004;1(1):7–25.
21. Krivo LJ, Peterson RD, Kuhl DC. Segregation, racial structure, and neighborhood violent crime. *Am J Sociol*. 2009;114(6):1765–802.
22. Brewer RM, Heitzeg NA. The racialization of crime and punishment: criminal justice, color-blind racism, and the political economy of the prison industrial complex. *Am Behav Sci*. 2008;51(5):625–44.
23. Carson E, Anderson E. Prisoners in 2015. *US Department of Justice Office of Justice Programs Bureau of Justice Statistics*; December 2016; 2017.
24. Pouget ER, Kershaw TS, Niccolai LM, Ickovics JR, Blankenship KM. Associations of sex ratios and male incarceration rates with multiple opposite-sex partners: potential social determinants of HIV/STI transmission. *Public Health Rep*. 2010;125(Suppl 4):70–80.
25. Sikkema KJ, Heckman TG, Kelly JA*, et al. HIV risk behaviors among women living in low-income, inner-city housing developments*. Am J Public Health. 1996;86(8_Pt_1):1123–1128.
26. Eberhart MG, Yehia BR, Hillier A, et al. Behind the cascade: analyzing spatial patterns along the HIV care continuum. *J Acquir Immune Defic Syndr*. 2013;64(Suppl 1):S42–51.
27. Williams DR, Collins C. Racial residential segregation: a fundamental cause of racial disparities in health. *Public Health Rep*. 2001;116(5):404–16.
28. Friedman SR, West BS, Tempalski B, Morton CM, Cleland CM, Des Jarlais DC, et al. Do metropolitan HIV epidemic histories and programs for people who inject drugs and men who have sex with men predict AIDS incidence and mortality among heterosexuals? *Ann Epidemiol*. 2014;24(4):304–11.
29. Massey DS, Denton NA. The dimensions of residential segregation. *Soc Forces*. 1988;67(2):281–315.
30. Acevedo-Garcia D. Residential segregation and the epidemiology of infectious diseases. *Soc Sci Med*. 2000;51(8):1143–61.
31. Biello KB, Kershaw T, Nelson R, Hogben M, Ickovics J, Niccolai L. Racial residential segregation and rates of gonorrhea in the United States, 2003-2007. *Am J Public Health*. 2012;102(7):1370–7.
32. Pugsley RA, Chapman DA, Kennedy MG, Liu H, Lapane KL. Residential segregation and gonorrhea rates in US metropolitan statistical areas, 2005-2009. *Sex Transm Dis*. 2013;40(6):439–43.
33. Singer JD, Willett JB. *Applied longitudinal data analysis: modeling change and event occurrence*New York: Oxford University Press, New York, NY; 2003.
34. Greenland S, Senn SJ, Rothman KJ, Carlin JB, Poole C, Goodman SN, et al. Statistical tests, P values, confidence intervals, and power: a guide to misinterpretations. *Eur J Epidemiol*. 2016;31(4):337–50.
35. Figueiredo Filho DB, Paranhos R, Rocha ECD, et al. When is statistical significance not significant? *Braz Polit Sci Rev*. 2013;7:31–55.
36. Ferguson CJ. An effect size primer: a guide for clinicians and researchers. *Prof Psychol Res Pract*. 2009;40(5):532–8.
37. Cooper HLF, West B, Linton S, et al. Contextual predictors of injection drug use among black adolescents and adults in US metropolitan areas, 1993–2007. *Am J Public Health*. 2015;106(3):517–26.
38. Yang J. *Interpreting coefficients in regression with log-transformed variables*. Ithaca, NY, USA: Cornell University; 2012.
39. Cooper HL, Linton S, Haley DF, et al. Changes in exposure to neighborhood characteristics are associated with sexual network characteristics in a cohort of adults relocating from public housing. *AIDS Behav*. 2015;19(6):1016–30.
40. An Q, Prejean J, Harrison KM, Fang XM. Association between community socioeconomic position and HIV diagnosis rate among adults and adolescents in the United States, 2005 to 2009. *Am J Public Health*. 2013;103(1):120–6.
41. Adimora AA, Schoenbach VJ. Contextual factors and the black-white disparity in heterosexual HIV transmission. *Epidemiology*. 2002;13(6):707–12.
42. Friedman SR, Cooper HL, Osborne AH. Structural and social contexts of HIV risk among African Americans. *Am J Public Health*. 2009;99(6):1002–8.
43. US Census Bureau. *American community survey and Puerto Rico community survey. 2016 subject definitions*. 2016.
44. Daly M, Hobijn B, Pedtke JH. Disappointing facts about the black-white wage gap. *FRBSF Econ Lett*. 2017;2017:26.
45. US Bureau Of labor statistics. *Labor Force Characteristics by Race and Ethnicity, 2012*. 2013.
46. US Bureau of Labor Statistics. *Characteristics of minimum wage workers*: *2012*. 2013.
47. Massey DS, Denton NA. Suburbanization and segregation in US metropolitan areas. *Am J Sociol*. 1988;94(3):592–626.
48. Kramer MR, Hogue CR. Is segregation bad for your health? *Epidemiol Rev*. 2009;31(1):178–94.
49. Mugavero MJ, Amico KR, Horn T, Thompson MA. The state of engagement in HIV care in the United States: from cascade to continuum to control. *Clin Infect Dis*. 2013;57(8):1164–71.