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Racial residential segregation and racial disparities in stillbirth in the United States

Andrew D. Williams^a, Maeve Wallace^b, Carrie Nobles^a, and Pauline Mendola^{a,*}

^aEpidemiology Branch, Division of Intramural Population Health Research, Eunice Kennedy Shriver National Institute of Child Health and Human Development, 6710B Rockledge, Bethesda, MD 20892, USA

^bDepartment of Global Community Health and Behavioral Sciences, Tulane University School of Public Health and Tropical Medicine, 1440 Canal Street, Suite 2210, New Orleans, LA 70117, USA

Abstract

We examined whether current and/or persistent racial residential segregation is associated with black-white stillbirth disparities among 49,969 black and 71,785 white births from the Consortium on Safe Labor (2002–2008). Black-white segregation was measured using the dissimilarity index and the isolation index, categorized into population-based tertiles. Using hierarchical logistic models, we found low and decreasing levels of segregation were associated with decreased odds of stillbirth, with blacks benefitting more than whites. Decreasing segregation may prevent approximately 900 stillbirths annually among U.S. blacks. Reducing structural racism, segregation in particular, could help reduce black-white stillbirth disparities.

Keywords

Racial residential segregation; Stillbirth; Racial disparities; Structural racism

1. Introduction

In the United States, approximately 24,000 stillbirths occur annually (Rowland Hogue and Silver, 2011; Macdorman and Gregory, 2015). Stillbirth rates in the U.S. have declined since the 1940s, yet a two-fold higher rate of stillbirth among non-Hispanic Blacks (henceforth blacks) compared to non-Hispanic Whites (henceforth whites) remains (Yankauer and

*Correspondence to: 6710B Rockledge, MSC 7004, Room 3119, Bethesda, MD 20892, USA. pauline.mendola@nih.gov (P. Mendola).

Description to obtain data

Consortium on Safe Labor data is publicly available at <https://dash.nichd.nih.gov/>. Geographic identifying information is not publicly available, see http://grants.nih.gov/grants/policy/data_sharing/ for National Institutes of Health data sharing policy.

Census and American Community Survey data is publicly available from The National Historical Geographic Information System at <https://www.nhgis.org/>.

Dartmouth Atlas of Healthcare geographic crosswalks are publicly available at <http://www.dartmouthatlas.org/tools/downloads.aspx?tab=39>.

Contact corresponding author for data access and code.

Conflict of interest

None declared.

Allaway, 1958; Macdorman and Gregory, 2015; Rowland Hogue and Silver, 2011). For example, in 2013, the stillbirth rate (per 1000 births) was 10.53 among blacks, and 4.88 among whites (Macdorman and Gregory, 2015). Racial disparities research has largely focused on individual-level determinants of stillbirth (i.e. sociodemographic characteristics, pregnancy risks), yet the black-white disparity persists (Rowland Hogue and Silver, 2011).

Structural racism, defined as public policies and institutional practices which reinforce racial inequalities, like residential black-white segregation (henceforth segregation) in the U.S., is suggested as a key determinant of racial health disparities since discriminatory policies have resulted in geographic separation by race, resulting in limited political power and limited access to resources and high crime among segregated black communities (Williams and Collins, 2001; Laveist, 1993; Lurie and Dubowitz, 2007; Bailey et al., 2017). Despite decreases in segregation in recent decades, segregation in the U.S. remains high (Reardon et al., 2009; Firebaugh and Acciai, 2016). For example, in 2010, half of the urban black population shared residential areas with only 3.6% of the urban non-black population (Firebaugh and Acciai, 2016). A lack of political power, limited access to resources and exposure to high rates of crime are hallmarks of stressful environments, and exposure to stress is hypothesized as a potential mechanism between segregation and racial disparities in birth outcomes (Osypuk and Acevedo-Garcia, 2008; Lu and Halfon, 2003; Lu et al., 2010). As segregation decreases, it is important to examine changes in persistent racial health disparities, like stillbirth, to evaluate whether changing social conditions lead to changes in health (Osypuk, 2013; Braveman, 2014).

Studies on segregation and stillbirth in the U.S., published in the 1950s, found a positive association between segregation and stillbirth among both blacks and whites residing in New York City (Yankauer, 1950; Yankauer and Allaway, 1958). More recent evidence from a statewide analysis in Georgia found high levels of segregation were associated with increased risk of stillbirth among blacks, yet were protective for whites (Brown Robert et al., 2012). Additionally, evidence from national samples of segregation and outcomes related to stillbirth (i.e. smoking during pregnancy (Yang et al., 2014), low birthweight (Austin et al., 2016), preterm birth (Osypuk and Acevedo-Garcia, 2008)) suggest blacks residing in high segregation areas have worse outcomes than whites residing in comparable areas. Similar race-specific associations have been observed between segregation and infant mortality (Bird, 1995; Polednak, 1991). However, extant studies regarding segregation and stillbirth are limited in their cross-sectional measures of segregation. As segregation is decreasing in the U.S., it is important to consider segregation as a dynamic exposure (Osypuk, 2013). Measures of persistent segregation can capture these changes in segregation, and provide evidence of risk or benefits associated with changing social environments.

Accumulating evidence of decreasing segregation and health suggests blacks benefit more from decreasing segregation than do whites. A longitudinal study of black adults found that exposure to decreases in segregation over a 25-year period was associated with lower blood pressure (Kershaw et al., 2017). Additionally, Civil Rights era social change (e.g. abolishing Jim Crow laws, War on Poverty) improved mortality rates (Krieger et al., 2013; Krieger et al., 2014; Chay and Greenstone, 2000; Almond et al., 2006) and life expectancy (Kaplan et al., 2006) more among blacks than among whites.

To better understand racial disparities in stillbirth in the U.S., we used data from 121,754 black and white births in the Consortium on Safe Labor, linked with U.S. census data, to examine race-specific associations between current segregation and stillbirth among blacks and whites. We also examined race-specific associations between persistent segregation and stillbirth among blacks and whites. We hypothesized that low and decreasing levels of segregation will be more beneficial to blacks than to whites.

2. Methods

The Consortium on Safe Labor (CSL) is an electronic medical record-based national retrospective cohort study from 2002 to 2008, which included 19 hospitals in 15 Hospital Reference Regions (HRR). Hospitals were selected based on availability of electronic medical records, and because the geographic distribution of the hospitals matched all United States districts of the American College of Obstetricians and Gynecologists (Zhang et al., 2010). Data extracted for births at 23 weeks or later include: maternal sociodemographic characteristics, medical, reproductive and prenatal history, labor and delivery, postpartum and newborn data. A total of 228,438 deliveries were included in the study. We excluded multifetal pregnancies ($n = 5053$; 2.21%), singleton pregnancies with missing exposure information ($n = 10$; .004%), and pregnancies from Utah due to the small number of black residents in our sample ($n = 49,376$; 21.61%) (Wallace et al., 2015). Including only black or white mothers resulted in an analytic sample of 121,754 births to 110,350 mothers from 14 hospitals in 12 HRRs. Institutional Review Boards at all participating sites approved the CSL and data are anonymous.

As individual addresses are not available in CSL data, residence is estimated using the HRR in which the birth occurred (Chen et al., 2014). In order to provide sociodemographic estimates at the HRR level, and as HRRs were partially defined by the aggregation of zip code tabulation area (ZCTA) data, we aggregated ZCTA data to the corresponding HRR using period-specific zip code to HRR crosswalks from the Dartmouth Atlas of Health Care (DAHC, 2013). ZCTA data was obtained from the 1990 and 2000 waves of the decennial Census, and the 2007–2011 wave of the American Community Survey (ACS) from the National Historical Geographic Information System (Manson et al., 2016). For estimation of current residential segregation, births in 2002–2004 were linked with 2000 Census data, and births in 2005–2008 were linked with 2007–2011 ACS data. For estimation of segregation in 1990, all births were linked with 1990 Census data.

Stillbirths were determined as fetal death 23 weeks gestation reported in medical records supplemented with ICD-9 codes.

There are two primary dimensions of segregation (Massey and Denton, 1988). The evenness dimension, the differential distribution of different racial/ethnic groups within a geographic area, is represented by the dissimilarity index (Table 1) (Massey and Denton, 1988; Reardon and O'sullivan, 2004). The exposure dimension, the probability that a member of one racial group will interact with a member of the same racial group, is represented by the isolation index (Table 1) (Massey and Denton, 1988; Reardon and O'sullivan, 2004). These measures of segregation have been more closely related to health outcomes than other segregation

measures (Yang and Matthews, 2015). Segregation measures were calculated separately for each wave of Census and ACS data.

For current segregation, tertiles were based on the population levels for the year of birth. For persistent segregation analyses, segregation tertiles were compared over time. For example, if the HRR remained in the same tertile between 1990 and birth year, that was considered persistent low, moderate, or high segregation. If the HRR moved to any lower tertile of segregation between 1990 and birth year, that was considered a decrease in segregation. If the HRR moved to any higher tertile of segregation between 1990 and birth year, that was considered an increase in segregation.

Measures of racial residential segregation are often calculated by aggregating census tract data to regional geographic units, such as Metropolitan Statistical Area level or counties, as these geographic levels allow for residential sorting (Kramer and Hogue, 2009). We aggregated ZCTA to HRR level, as HRR is the geographic unit in CSL data, and no crosswalk is available to aggregate smaller geographic units, like census tracts, to the HRR level (Chen et al., 2014; Dahc, 2013). Aggregating ZCTAs to provide estimates at the HRR level reflects methods used in defining HRRs (Dahc, 2013). Furthermore, the HRR is a large enough geographic area to allow for residential sorting. For instance, the 356 Metropolitan Statistical Areas in Census 2000 data have an average size of 2147.73 square miles (Bureau, 2017). The average size of the 12 HRRs included in this analysis is 12,128.26 square miles. All HRRs are defined based on population centers with at least 120,000 residents (Dahc, 2013). Thus, HRRs are an appropriate geographic level to examine segregation.

Individual-level covariates included maternal age in years, marital status (married, single, divorced, missing), birth year, insurance status (public, private, other) as measure of maternal socioeconomic status, pre-pregnancy Body Mass Index (BMI, < 18.5, 18.5- < 25, 25- < 30, 30), smoking in pregnancy (yes, no), alcohol use in pregnancy (yes, no), prior stillbirth (yes, no), prior pregnancy risks (previous c-section, prior preterm birth), current pregnancy risks (small for gestational age, preterm birth, placental abruption), and preconception chronic disease (asthma, hypertension, diabetes). Race was not included as race-specific models were fit. In extant literature, these covariates are associated with racial disparities in stillbirth (Rowland Hogue and Silver, 2011). Missing data were retained as their own category.

Average exposure to ozone (O₃) during pregnancy (Mendola et al., 2017) and average temperature during pregnancy (Ha et al., 2017) have been previously linked with stillbirth, and were included as area-level covariates. HRR-level poverty (proportion of residents in the HRR living below federal poverty thresholds) was included as a potential confounder in the association between segregation and poor birth outcomes (Osypuk and Acevedo-Garcia, 2008; Austin et al., 2016; Yang et al., 2014). Percent change in HRR-level poverty from 1990 to birth year was included in persistent segregation models. All area-level covariates were treated as continuous.

2.1. Statistical Analysis

A series of 2-level hierarchical, women within HRRs, logistic regression models accounting for study site and using robust standard errors to account for repeated births to the same mother ($n = 7198$ white, 10% of whites; 4184 black, 8% of blacks), estimated the association between segregation and stillbirth. First, models were fit to estimate the association between current segregation levels and stillbirth. Model A included current segregation, maternal age, insurance status, birth year and marital status. Model B added smoking in pregnancy, alcohol use in pregnancy, pre-pregnancy BMI, prior stillbirth, prior pregnancy risks, current pregnancy risks, and preconception chronic disease. Model C added current percent poverty, temperature, and ozone.

Second, models were fit to estimate the association between persistent segregation and stillbirth. Model D included persistent segregation, maternal age, insurance status, birth year and marital status. Model E added smoking in pregnancy, alcohol use in pregnancy, pre-pregnancy BMI, prior stillbirth, prior risks, current risks, and preconception chronic disease. Model F added current percent poverty, change in poverty over time, temperature, and ozone.

Fully-adjusted current segregation models were specified in Eq. (1).

$$\begin{aligned}
 x_{ij} = & \gamma_{00} + \gamma_{01}(\text{Moderate Segregation}_j) + \gamma_{02}(\text{Low Segregation}_j) \\
 & + \gamma_{03}(\text{Temperature}_j) + \gamma_{04}(\text{Ozone}_j) + \gamma_{05}(\text{Poverty}_j) \\
 & + \begin{bmatrix} \gamma_{1j} \\ \cdots \\ \gamma_{xj} \end{bmatrix} \begin{bmatrix} X_{1ij} \cdots & X_{nij} \end{bmatrix} + r_{ij} + u_{0j}
 \end{aligned} \tag{1}$$

Fully-adjusted persistent segregation models are specified in Eq.(2):

$$\begin{aligned}
 x_{ij} = & \gamma_{00} + \gamma_{01}(\text{Persistent Moderate Segregation}_j) \\
 & + \gamma_{02}(\text{Persistent Low Segregation}_j) + \gamma_{03}(\text{Decreasing Segregation}_j) \\
 & + \gamma_{04}(\text{Increasing Segregation}_j) + \gamma_{05}(\text{Temperature}_j) + \gamma_{06}(\text{Ozone}_j) \\
 & + \gamma_{07}(\text{Poverty}_j) + \gamma_{08}(\text{Change in Poverty}_j) + \begin{bmatrix} \gamma_{1j} \\ \cdots \\ \gamma_{xj} \end{bmatrix} \begin{bmatrix} X_{1ij} \cdots & X_{nij} \end{bmatrix} \\
 & + r_{ij} + u_{0j}
 \end{aligned} \tag{2}$$

X_{ij} is the log transformation of the predicted probability of stillbirth. γ_{00} is the intercept, with γ_{01-0n} being the effect of area-level predictors and covariates on the intercept.

$\begin{bmatrix} \gamma_{1j} \\ \dots \\ \gamma_{xj} \end{bmatrix} \begin{bmatrix} X_{1ij} \dots X_{nij} \end{bmatrix}$ is the matrix of individual – level covariates. r_{ij} is the individual-level residual, and u_{0j} is the area-level residual.

The above sequence of models was run for both the dissimilarity index, and the isolation index. High segregation served as the reference. Separate models were fit by race to identify race-specific associations between segregation and stillbirth (Krieger et al., 2013; Krieger et al., 2014; Clark and Williams, 2016). This allows for a better understanding of race-specific experiences within a context of geographically-based racial inequality, like segregation (Clark and Williams, 2016). Resulting odds ratios (OR) were interpreted as the odds of stillbirth occurring. Race*segregation interaction terms were included in an overall model to explore significant differences by race in the association between segregation and stillbirth.

We calculated population attributable fraction (PAF) for exposure to decreased segregation from 1990 to birth year using the following formula (Rockhill et al., 1998):

$$PAF = pd_i \left(\frac{OR_i - 1}{OR_i} \right)$$

Pd_i is the proportion of cases exposed to decreased segregation, and OR_i is the adjusted OR of the association between decreased segregation and stillbirth. PAF was interpreted as the proportion of estimated fewer stillbirths associated with decreased segregation. The estimate of number of fewer stillbirths was obtained by applying PAF to study data and national fetal mortality data (Macdorman and Gregory, 2015).

Given the relatively small number of HRRs ($n = 12$), we conducted sensitivity analyses to determine if the observed associations were largely driven by a single HRR. We fit models leaving each HRR out in turn and examined the findings with the remaining 11 HRRs to determine if there was a qualitative change in results. Data analyses were performed using SAS 9.4.

3. Results

Table 2 presents distribution of stillbirths by race. There were 336 stillbirths (6.7 per 1000 births) among blacks and 209 stillbirths (2.9 per 1000 births) among whites ($P < 0.001$).

Blacks had significantly higher rates of stillbirth than whites by individual- and area-level covariates, except for alcohol use and area-level poverty (Table 2). Among women with prenatal alcohol use, whites (9.2 per 1000 births) had a higher rate of stillbirth than blacks (8.3 per 1000 births) ($p = 0.024$). There was no difference in stillbirth rates by area-level poverty. HRR segregation levels and poverty levels are included in Table 3.

Black-white differences in stillbirth rates by level of segregation were observed. As current segregation levels increase, stillbirth rates increase for both blacks and whites (Table 2). However, at each level of current segregation, blacks have a significantly higher rate of

stillbirth than whites (Table 2). Among levels of persistent segregation, blacks have a consistent two-fold higher stillbirth rate than whites, with blacks residing in persistent high segregation areas having the highest rates of stillbirth (Table 2). Of note is that the black-white difference in stillbirth rates differs by measure of decreasing segregation. In areas of decreasing dissimilarity, blacks (5.8 per 1000 births) have a higher rate of stillbirth than whites (3.9 per 1000 births) ($P < 0.001$), while in areas of decreasing isolation, blacks have a slightly lower stillbirth rate (2.1 per 1000 births) than whites (2.6 per 1000 births) ($P < 0.001$).

In current segregation analysis (Table 4), compared to high levels of segregation, low levels of segregation were associated with a greater reduction in odds of stillbirth among blacks than among whites, in both dissimilarity and isolation analysis. For example, regardless of socio-demographic, health risk or area-level covariates (Model C), low levels of dissimilarity are associated with 57% reduced odds of stillbirth among blacks, but is not significantly associated with stillbirth among whites (interaction $p < 0.05$). In fully adjusted isolation models (Model C), low levels of isolation are associated with 75% reduced odds of stillbirth among blacks, marginally stronger than the 67% reduced odds of stillbirth among whites.

Compared to high levels of dissimilarity, moderate levels of dissimilarity were associated with decreased odds of stillbirth for blacks and whites, and this association is somewhat stronger among whites (Model C). Moderate levels of isolation were associated with 39% reduced odds of stillbirth among blacks only (Model C).

In persistent segregation analysis (Table 5), decreasing segregation is significantly associated with reduced odds of stillbirth among blacks, but not whites. In dissimilarity models, blacks experience a 47% reduction in odds of stillbirth, regardless of sociodemographic, health risk, or area-level covariates (Model F). Similarly, in fully adjusted models (Model F), a decrease in isolation is associated with approximately 80% reduced odds of stillbirth among blacks only.

Persistent moderate levels of dissimilarity are associated with reduced odds of stillbirth among both blacks and whites, similar to the reductions in odds for both blacks and whites we observe in areas of persistent low isolation (interaction $p < 0.05$) (Table 5, Model F).

Adjusting for covariates changes the association between persistent segregation and stillbirth more among whites than blacks (Table 5). For example, among whites, inclusion of health risks increased the OR for persistent low dissimilarity from 0.54 to 1.22 and the association become non-significant (model D compared to model E). Inclusion of area-level covariates further increased the OR for persistent low dissimilarity from 1.22 to 1.50 (model E compared to model F). Among blacks, the addition of health risks and area-level covariates did not substantively change the OR for persistent low dissimilarity.

Population attributable risk estimates suggest decreasing segregation over time could result in 8–15% fewer stillbirths among blacks, but no significant decrease in stillbirths among whites would be observed (Table 6). Given recent U.S. stillbirth data, (Macdorman and Gregory, 2015) this suggests approximately 932 (95% CI: 311, 1989) fewer cases of stillbirth among blacks could be avoided with decreasing segregation.

Results of sensitivity analyses that evaluated the impact of removing the Utah sites and sequentially removed each HRR from the model were similar to the main study findings (data not shown).

4. Discussion

Despite decreasing levels of segregation in recent decades, the U.S. remains a highly segregated society (Reardon et al., 2009; Firebaugh and Acciai, 2016). In a large, contemporary U.S. obstetric cohort, we find that lower levels of both current and persistent segregation indices are associated with significant reductions in stillbirth risk for blacks with little significant change among whites. As segregation is considered a key determinant of racial health disparities, it is opportune to reexamine the persistent racial disparity in stillbirth in the context of decreasing segregation (Braveman, 2014; Osypuk, 2013; Williams and Collins, 2001; Lurie and Dubowitz, 2007). These findings have important population health implications as only one study of segregation and stillbirth has been conducted since the 1950s (Brown Robert et al., 2012; Yankauer, 1950; Yankauer and Allaway, 1958). This is the first study of segregation and stillbirth to include a national sample, and no prior studies have considered persistent segregation and stillbirth.

Our results suggest low levels of segregation were more beneficial to blacks than whites. One recent study of segregation and stillbirth in Georgia found high levels of segregation increase risk of stillbirth among blacks, but may be protective among whites (Brown Robert et al., 2012). At all levels of segregation, blacks had an increased risk of stillbirth compared to whites, yet the increased risk among blacks was smaller in areas with low levels of segregation than in areas of high levels of segregation (Brown Robert et al., 2012), which our findings reflect. These recent findings specific to stillbirth are in line with recent evidence among national samples suggesting segregation predicts smoking during pregnancy (Yang et al., 2014), birthweight, (Austin et al., 2016) preterm birth (Osypuk and Acevedo-Garcia, 2008) and infant mortality (Bird, 1995, Polednak, 1991) among blacks but not whites. These more recent findings differ from results from the 1950s, which found increasing levels of segregation were associated with higher stillbirth rates for both blacks and whites residing in New York City (Yankauer, 1950; Yankauer and Allaway, 1958). These early data, collected during the nascent stages of the Civil Rights Era (between 1945 and 1955), reflect a period when levels of segregation approached their peak in the U.S. (Shertzer and Walsh, 2016). More recent studies (data collected between 1982 and 2008) (Yang et al., 2014; Osypuk and Acevedo-Garcia, 2008; Austin et al., 2016; Bird, 1995; Polednak, 1991; Brown Robert et al., 2012) suggest social changes (e.g. abolition of Jim Crow, more equitable housing markets) during the Civil Rights Era were more beneficial to the blacks than whites. This finding is also reflected in studies that have examined decreasing segregation over time.

We found that a relative decrease in segregation between 1990 and birth year was associated with approximately 80% reduced odds of stillbirth among blacks, with no change in odds of stillbirth among whites (Table 5). While our study did not capture maternal residence over time, we found evidence that area-level changes over time are associated with health outcomes. Specifically, HRRs with decreasing levels of segregation had lower rates of

stillbirth and decreasing black-white disparity in stillbirth. This is consistent with evidence examining other health outcomes associated with decreasing segregation over time. A longitudinal study among black adults found individuals exposed to lower levels of segregation over a 25-year period had lower systolic blood pressure (Kershaw et al., 2017). Studies examining black-white health disparities before and after the Civil Rights Act suggest that blacks experienced a greater benefit from the elimination of legal discrimination than whites (Krieger et al., 2013; Krieger et al., 2014; Chay and Greenstone, 2000; Almond et al., 2006; Kaplan et al., 2006). For example, abolition of Jim Crow laws was associated with lower premature mortality rates and infant mortality rates more so among blacks than among whites (Krieger et al., 2013; Krieger et al., 2014).

In the current study, race-specific associations between segregation and stillbirth were observed even after adjustment for a range of individual-level factors, including socioeconomic status, health behaviors and medical risks, as well as area-level factors including HRR-level poverty, average exposure to ozone and average temperature during pregnancy. (Mendola et al., 2017; Ha et al., 2017) These race-specific associations were observed across distinct dimensions of segregation, in line with evidence suggesting the relationship between segregation and health outcomes is multifaceted (Acevedo-Garcia et al., 2003). Concentrated area-level poverty in highly segregated areas has been cited as a potential link between segregation and poor birth outcomes (Osypuk and Acevedo-Garcia, 2008; Austin et al., 2016; Yang et al., 2014), yet the association between segregation and stillbirth remains after inclusion of area-level poverty. This suggests area-level poverty, as measured at the HRR level, does not fully account for the potential relationship between segregation, area-level poverty, and stillbirth. Exposure to chronic stress associated with residing in a highly segregated area has been suggested as a potential mechanism between segregation and racial disparities in birth outcomes (Osypuk and Acevedo-Garcia, 2008; Lu and Halfon, 2003; Lu et al., 2010). Historically, black communities are more segregated, and segregated areas are considered to be stressful environments due to high crime, limited political power and limited access to resources (Williams and Collins, 2001; Laveist, 1993; Lurie and Dubowitz, 2007; Osypuk and Acevedo-Garcia, 2008; Lu and Halfon, 2003; Lu et al., 2010). Exposure to individual-level stress (e.g. death of a family member) during pregnancy is associated with elevated risk of stillbirth (László et al., 2013), and area-level stressors like area-level socioeconomic status have been linked with stillbirth (Guildea et al., 2001). Evidence suggests exposure to stress during pregnancy may be associated with placental dysfunction (László et al., 2013; Klonoff-Cohen et al., 1996; De Paz et al., 2011). As placental dysfunction can precede stillbirth (Flenady et al., 2011; Rowland Hogue and Silver, 2011), biologic plausibility for the link between segregation and stillbirth exists. However, these mechanisms remain to be explored. In areas of decreasing segregation, it seems reasonable that women may be exposed to lower levels of stress during pregnancy, partially explaining lower odds of stillbirth.

Among whites, the association between segregation and stillbirth is inconsistent. Results suggest whites may benefit from lower levels of segregation, but factors other than segregation may be more predictive of stillbirth among whites, evidenced by the significant changes in the ORs with introduction of individual- and area-level covariates (Tables 4 and

5). Stillbirth is less common among whites than blacks, and estimates are therefore less precise for whites.

The pattern of association between segregation and stillbirth was similar for dissimilarity and isolation analyses, yet the strength of association is consistently stronger in isolation analysis (Tables 4 and 5). Dissimilarity does not consider the racial/ethnic composition of the area, only how racial/ethnic groups are distributed within an area (Massey and Denton, 1988; Reardon and O'sullivan, 2004). In contrast, isolation attempts to measure the experience of segregation by incorporating the racial composition of the area (Massey and Denton, 1988; Reardon and O'sullivan, 2004). For example, if blacks make up a large proportion of the population, they may experience greater isolation from other racial/ethnic groups (Massey and Denton, 1988; Reardon and O'sullivan, 2004). Thus, the stronger association observed in isolation analyses may be a reflection of the isolation index better capturing the experience of segregation.

In sensitivity analysis we explored whether the observed associations between segregation and stillbirth were driven by one or more HRRs. Excluding any HRR from the analytic sample did not result in any meaningful change in the observed associations. This is reassuring and suggests that the observed associations between segregation and stillbirth reflect the entire nationwide sample.

Even though segregation in the U.S. remains high, small changes in ubiquitous exposures like segregation can have important population health implications. For example, decreasing segregation could account for approximately 500–900 fewer stillbirths annually among blacks (Table 6). However, despite the benefit of decreasing segregation experienced by blacks, black-white disparity in stillbirth persists.

Our findings, in the context of previous evidence of race/ethnic-specific associations between structural racism and birth outcomes, highlight the pervasive and historic challenges facing racial/ethnic minority communities in the U.S. Research should acknowledge the role of structural racism and identify aspects of society that, in spite of social reforms, uphold structural racism and contribute to racial/ethnic health disparities in the U.S.

Additionally, future research should acknowledge the racial/ethnic minority communities often overlooked in studies of health disparities. For example, U.S.-based Hispanic populations and Asian populations often face similar forms of structural racism as black populations (Iceland et al., 2014), yet the health consequences associated with structural racism among these groups are not as well understood. Focusing on structural racism among these overlooked populations will provide an understanding of the context in which health outcomes play out in these unique communities in the U.S. We were unable to address this in our data due to the small number of cases in other race/ethnic groups.

4.1. Limitations

With medical record data, it is possible that unmeasured confounders that might increase stillbirth risk were unavailable. However, the rich clinical data do allow us to control for

socioeconomic status, a range of maternal health behaviors and medical risks associated with racial disparities in stillbirth (Rowland Hogue and Silver, 2011), and we included novel area-level covariates like ozone and temperature (Mendola et al., 2017; Ha et al., 2017). This study is also limited by CSL's cross-sectional design, prohibiting causal conclusions. However, findings are in line with longitudinal data suggesting decreasing segregation is beneficial to blacks (Kershaw et al., 2017).

Our measures of segregation – dissimilarity and isolation – are limited in that they only account for the distribution of black and white residents of the HRRs, and do not consider residents of other racial/ethnic backgrounds. Additionally, these measures of segregation do not account for the spatial distribution of segregation within each HRR. Given that HRR is the geographic unit of analysis in the CSL, we were not able to address the potential relationship between spatial differences in segregation within an HRR and stillbirth. However, given the geographic limitations of CSL data, we were able to calculate segregation measures by aggregating ZCTAs to the HRR level. While this method differs from other calculations of segregation (Kramer and Hogue, 2009), the use of ZCTAs reflects how residents are sorted within an HRR, and provides variability in the levels of segregation in our data (Table 3).

As HRR is the area of residence in the CSL, we are unable to examine area-level poverty at smaller geographic levels or examine clusters of high poverty within HRRs. As HRR level poverty was a statistically significant determinant of stillbirth, the effects of area-level poverty may be stronger when measured at a smaller geography. The lack of maternal residence history limited assessment of lifetime exposure to segregation. Most moves occur within the same area, thus, cross-sectional data may allow reasonable estimates of exposure to segregation over time (Osypuk, 2013).

5. Conclusion

In the first nationwide examination of segregation and stillbirth, we observed low and decreasing levels of segregation over time were more beneficial to blacks than to whites. Decreasing segregation accounted for approximately 900 prevented stillbirths annually among blacks, with little change in stillbirth among whites. Despite the improvements seen in segregation, the black-white disparity in stillbirth remains. These findings suggest reducing structural racism, like segregation, can improve health outcomes for blacks, and could potentially reduce persistent racial health disparities.

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Table 1

Measures of Racial Residential Segregation.

Measure	Formula	Interpretation
Dissimilarity Index Score Range: 0 – 1, <i>I</i> = high dissimilarity	$Dissimilarity = \frac{1}{2} \sum_{i=1}^n \left \frac{w_i}{W_T} - \frac{b_i}{B_T} \right $	Score of 0.6 suggests 60% of Black residents of an HRR would need to move to different Zip codes within their HRR of residence in order for blacks and whites to be evenly dispersed in that HRR.
Isolation Index Score Range: 0 – 1, <i>I</i> = high isolation	$Isolation = \sum_{i=1}^n \left(\frac{b_i}{B_T} \right) * \left(\frac{b_i}{P_T} \right)$	If blacks make up 25% of the population of an HRR, but all blacks live in Zip codes that are 100% black, the isolation index would be equal to 1.
Components	Description	
b_i	Number of blacks in the Zip code	
B_T	Number of blacks in the HRR	
n	Number of Zip codes	
P_T	Total population of the HRR	
W_i	Number of whites in the Zip code	
W_T	Number of white in the HRR	

Table 2
Stillbirth Frequencies and Rates by Individual- and Area-Level Covariates (Black n = 49969; White n = 71785).

	Black stillbirths	Black stillbirth rate per 1000 ^a	White stillbirths	White Stillbirth rate per 1000 ^a	P value ^b
Total	336	6.7	209	2.9	< 0.001
Maternal age					< 0.001
< 18 years	25	7.7	6	5.2	
18–24 years	131	6.1	63	3.5	
25–29 years	62	5.2	54	2.9	
30–34 years	64	8.1	38	1.9	
35–40 years	40	9.2	36	3.0	
40+ years	14	10.7	12	3.9	
Insurance type					< 0.001
Other	82	12.6	36	4.6	
Public	154	5.8	59	4.1	
Private	100	5.8	114	2.2	
Marital status					< 0.001
Missing	34	25.9	14	7.9	
Divorced	5	8.0	6	4.6	
Single	229	6.3	68	4.0	
Married	68	5.7	121	2.3	
Smoking during pregnancy					0.013
Yes	37	9.1	32	4.7	
No/Unknown	299	6.5	177	2.7	
Alcohol use during pregnancy					0.024
Yes	8	8.3	12	9.2	
No/Unknown	328	6.6	197	2.7	
Body mass index					< 0.001
30	56	6.3	13	2.2	
25- < 30	49	6.3	18	2.3	
18.5- < 25	71	5.7	39	1.7	
< 18.5	10	8.4	4	1.6	

	Black stillbirths	Black stillbirth rate per 1000 ^a	White stillbirths	White stillbirth rate per 1000 ^a	P value ^b
Unknown	150	7.4	135	4.0	
Preconception disease					
Yes	81	10.2	34	4.9	< 0.001
No	255	6.0	175	2.6	
Prior pregnancy risk					
Yes	87	7.6	38	3.1	< 0.001
No	215	6.3	154	2.8	
Unknown	34	7.1	17	2.7	
Current pregnancy risk					
Yes	124	15.9	81	11.7	< 0.001
No	212	5.0	128	1.9	
Prior Stillbirth					
Yes	8	9.0	2	4.1	< 0.001
No	134	6.0	44	1.8	
Unknown	194	7.1	163	3.4	
Current dissimilarity index					
Low	53	3.2	59	2.8	< 0.001
Moderate	119	8.3	89	2.8	
High	164	8.4	61	3.1	
Current isolation index					
Low	25	2.7	43	1.8	< 0.001
Moderate	139	7.1	107	3.3	
High	172	8.0	59	3.5	
Persistent dissimilarity index					
Stay Low	108	5.6	37	2.6	< 0.001
Stay Mod	33	5.2	64	2.4	
Stay High	164	8.4	61	3.1	
Decrease	31	5.8	47	3.9	
Persistent Isolation Index					
Stay Low	17	3.8	41	1.9	< 0.001
Stay Mod	94	7.3	35	4.0	

	Black stillbirths	Black stillbirth rate per 1000 ^a	White stillbirths	White stillbirth rate per 1000 ^a	P value ^b
Stay High	172	8.0	59	3.5	
Decrease	12	2.1	34	2.6	
Increase	41	7.0	40	3.3	
Temperature					< 0.001
Low	67	14.5	51	6.7	
Moderate	189	5.2	146	2.3	
High	80	8.3	12	4.5	
Poverty					0.30
Above Median	190	8.2	89	2.6	
Below Median	146	5.4	120	3.0	
Change in poverty					< 0.001
Above Median	91	5.8	117	2.6	
Below Median	245	7.1	92	3.3	
Ozone					< 0.001
Above Median	201	8.0	127	3.5	
Below Median	135	5.3	83	2.3	

^aStillbirth rates category specific and do not equal overall stillbirth rate.

^bP-values obtain using generalized estimating equations to account for women who had more than one pregnancy in the study.

Table 3

Hospital Referral Region Segregation Levels and Poverty Levels.

HRR location	1990 Census dissimilarity	2000 Census dissimilarity	2005–2008 ACS dissimilarity	1990 Census isolation	2000 Census isolation	2005–2008 ACS isolation	1990 Census poverty	2000 Census poverty	2005–2008 ACS poverty
Los Angeles, CA	0.65	0.64	0.62	0.39	0.30	0.26	14.79	17.53	16.00
Newark, DE	0.45	0.44	0.44	0.35	0.36	0.36	8.13	8.54	10.69
Washington, DC ^a	0.72	0.72	0.67	0.70	0.68	0.63	8.65	9.51	8.86
Miami, FL	0.61	0.62	0.58	0.49	0.46	0.44	16.22	15.99	16.05
Chicago, IL	0.74	0.75	0.76	0.75	0.72	0.70	21.50	19.54	21.43
Indianapolis, IN	0.69	0.67	0.64	0.41	0.39	0.35	10.40	8.88	13.66
Baltimore, MD ^a	0.62	0.59	0.56	0.57	0.57	0.55	10.37	10.16	10.57
Springfield, MA	0.63	0.66	0.64	0.31	0.25	0.20	11.34	12.17	14.05
Brooklyn, NY	0.68	0.76	0.74	0.61	0.57	0.54	19.55	21.54	19.11
Akron, OH	0.65	0.65	0.63	0.42	0.40	0.39	11.88	9.94	14.41
Cleveland, OH	0.75	0.73	0.71	0.64	0.61	0.59	11.47	10.43	13.96
Houston, TX	0.51	0.55	0.52	0.42	0.37	0.32	15.25	13.74	15.39

^a 2 hospitals in this location are included in the Consortium on Safe Labor.

Table 4

Race-specific Associations Between Current Levels Segregation and Stillbirth in the Consortium on Safe Labor (Odds Ratios and 95% Confidence Intervals).

		Model A				Model B				Model C			
		Black N = 49,969		White N = 71,785		Black N = 49,969		White N = 71,785		Black N = 49,969		White N = 71,785	
		OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Dissimilarity													
High	Ref.			Ref.		Ref.		Ref.		Ref.		Ref.	
Moderate	0.86	0.67, 1.11	0.63	0.44, 0.90	0.89	0.67, 1.18	0.71	0.49, 1.02	0.51	0.33, 0.78	0.33	0.20, 0.55	
Low	0.36	0.26, 0.49 [*]	0.72	0.50, 1.04	0.37	0.27, 0.51 [*]	0.94	0.63, 1.38	0.43	0.29, 0.63 [*]	1.42	0.77, 2.59	
Isolation													
High	Ref.			Ref.		Ref.		Ref.		Ref.		Ref.	
Moderate	0.82	0.64, 1.04	1.11	0.81, 1.54	0.82	0.65, 1.05	1.16	0.87, 1.70	0.61	0.42, 0.91	1.06	0.71, 1.59	
Low	0.26	0.17, 0.41	0.40	0.26, 0.61	0.28	0.18, 0.44	0.56	0.36, 0.86	0.25	0.16, 0.41	0.33	0.21, 0.53	

Model A includes age, birth year, insurance status, marital status. Model B includes covariates in Model A, plus smoking in pregnancy, alcohol use in pregnancy, pre-pregnancy BMI, prior stillbirth, stillbirth risks in prior pregnancy (previous c-section, prior preterm birth), current risks (small for gestational age, preterm birth, placental abruption), preconception chronic disease (asthma, hypertension, diabetes). Model C includes covariates in Model B, plus current area-level percent poverty, exposure to ozone, and temperature.

* Association different among blacks than whites (interaction p-value < .05).

Table 5

Race-specific Associations Between Persistent Levels Segregation and Stillbirth in the Consortium on Safe Labor (Odds Ratios and 95% Confidence Intervals).

	Model D				Model E				Model F			
	Black N = 49,969		White N = 71,785		Black N = 49,969		White N = 71,785		Black N = 49,969		White N = 71,785	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Dissimilarity												
Stay High	Ref.		Ref.		Ref.		Ref.		Ref.		Ref.	
Stay Moderate	0.53	0.36, 0.77	0.70	0.46, 1.06	0.55	0.37, 0.81	0.68	0.46, 1.00	0.37	0.23, 0.60	0.34	0.21, 0.57
Stay Low	0.58	0.45, 0.74	0.54	0.37, 0.79	0.58	0.45, 0.76	1.22	0.77, 1.94	0.51	0.33, 0.79	1.50	0.80, 2.80
Any Decrease	0.68	0.46, 1.00	0.86	0.58, 1.29	0.62	0.41, 0.93	0.73	0.47, 1.11	0.53	0.32, 0.89*	0.75	0.41, 1.37
Isolation												
Stay High	Ref.		Ref.		Ref.		Ref.		Ref.		Ref.	
Stay Moderate	0.78	0.60, 1.03	1.08	0.71, 1.65	0.78	0.59, 1.03	1.15	0.74, 1.78	0.46	0.28, 0.75	0.74	0.43, 1.27
Stay Low	0.39	0.23, 0.64	0.45	0.29, 0.70	0.43	0.26, 0.71	0.61	0.40, 0.95	0.41	0.23, 0.73	0.35	0.21, 0.57
Any Decrease	0.21	0.11, 0.39*	1.00	0.64, 1.55	0.22	0.11, 0.41*	0.97	0.62, 1.52	0.19	0.10, 0.38*	0.82	0.46, 1.48
Any Increase	0.94	0.66, 1.33	0.97	0.64, 1.45	0.97	0.68, 1.38	1.34	0.86, 2.07	1.58	0.83, 3.04	1.72	0.80, 3.66

Model D includes age, birth year, insurance status, marital status. **Model E** includes covariates in Model D, plus smoking in pregnancy, alcohol use in pregnancy, pre-pregnancy BMI, prior stillbirth, stillbirth risks in prior pregnancy (previous c-section, prior preterm birth), current risks (small for gestational age, preterm birth, placental abruption), preconception chronic disease (asthma, hypertension, diabetes). **Model F** includes covariates in Model E, plus current area-level percent poverty, change in poverty from 1990 to birth year, exposure to ozone, and temperature.

* Association different among blacks than whites (interaction p-value < .05).

Population Attributable Risk of Decreased Segregation and Estimated Fewer Stillbirths (Estimates and 95% Confidence Intervals).

Table 6

Population attributable risk		Fewer stillbirths in study data		Fewer stillbirths 2002–2008 in United States		Fewer stillbirths 2013 in United States		
PAR	95% CI	n	95% CI	n	95% CI	n	95% CI	
Decrease in dissimilarity								
Black	−0.08	−0.19, −0.01	27	3.36, 63.84	3763	470.37, 8937.03	498	62.16, 1181.04
White	−0.07	−0.13, 0.02	–	–	–	–	–	–
Decrease in isolation								
Black	−0.15	−0.32, −0.05	50	16.80, 107.52	7056	2351.85, 15,051.84	932	310.80, 1989.12
White	−0.03	−0.19, 0.05	–	–	–	–	–	–

^aPopulation Attributable Risk calculated with the following formula: $PAF = p d_i \left(\frac{OR_i - 1}{OR_i} \right)$.

$p d_i$ is the proportion of cases exposed to decreased segregation, and OR_i is the adjusted odds ratio of the association between decreased segregation and stillbirth.