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Contribution of county-level socioeconomic indicators to racial or ethnic differences in neonatal anthropometry in the USA: a prospective cohort study

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ABSTRACT

Introduction Racial and ethnic differences in fetal growth and birth size in the USA have not been adequately explained by individual-level socioeconomic status (SES) factors. We explored whether differences may be partially explained by county-level indicators of SES.

Methods We linked participant zip codes from the National Institute of Child Health and Human Development Fetal Growth Studies (2009–2013; n=1614) to county-level US census data to calculate a neighbourhood deprivation index, education isolation index and two indices of segregation: racial isolation and evenness. Using causal mediation methods, we evaluated the extent to which racial/ethnic differences in neonatal anthropometrics could be eliminated in a hypothetical setting where everyone lived in counties with high resource availability and racial/ethnic integration.

Results Setting racial evenness to levels consistent with the highest diversity eliminated 79.9% of the difference in birth weight between non-Hispanic White and non-Hispanic Black and all the difference (106.3%) in birth weight between Hispanic and non-Hispanic White individuals. Setting racial evenness, racial isolation and education isolation to levels consistent with higher diversity and education was also associated with similar reductions in differences for other anthropometric measures.

Conclusions Our findings suggest that, in a hypothetical scenario where everyone lived in counties with low deprivation or segregation, race/ethnic differences in neonatal anthropometry may substantially decrease or be eliminated. Our results also highlight the importance of considering community-level and structural factors in analyses of race/ethnic health disparities.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Area-level socioeconomic factors are associated with racial and ethnic disparities in birth size, but the extent to which disparities may be eliminated in a setting of equality has not been explored.

WHAT THIS STUDY ADDS

⇒ We expand on current knowledge of disparities by adopting a causal mediation framework to create a hypothetical scenario in which participants of all racial or ethnic groups lived in neighbourhoods with the highest resource availability and the lowest segregation.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The totality of evidence suggests that if all racial and ethnic groups in the USA lived in areas with high resource availability and racial and ethnic diversity, disparities in birth size may be substantially decreased or eliminated, which has a substantial impact on policies to promote equality.

INTRODUCTION

Racial and ethnic disparities in birth outcomes in the USA are well-documented and a pressing public health issue.[1] Neonatal size, including birth weight, is influenced by a variety of factors, and growing evidence, including studies of ancestry and nativity,[2–4] supports that important contributors to race/ethnic differences in birth outcomes are social and environmental factors.[5] Furthermore, lifecourse theories,[6] and specifically, Developmental Origins of Health and Disease theories,[7] suggest that exposure to social and environmental factors, such as poverty, neighbourhood deprivation and residential racial segregation during the periods of preconception and pregnancy may adversely influence normal developmental trajectories. Subsequent dysregulation of organ development and homeostatic systems may be implicated in the formation and perpetuation of disparities in birth outcomes that often lead to disparities in adult health outcomes.[6 8 9]

In our previous work in the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD) Fetal Growth Studies, we found that individual socioeconomic factors did not account for differences in racial/ethnic variation in neonatal anthropometry.[10] However, race/ethnic differences in neonatal anthropometry are likely influenced by complex associations between both individual and area-level socioeconomic status (SES) indicators.[11] In fact, a growing body of literature emphasises the important contribution of area-level factors, such as neighbourhood deprivation and racial residential segregation in the formation of race/ethnic disparities in birth outcomes.[5 12] However, most existing literature considers only the interaction between race and SES, and has not evaluated how disparities may be explained or influenced by area-level SES indicators. Thus, using county-level indicators of SES and segregation, we conducted mediation analyses to evaluate the extent to which race/ethnic differences in neonatal anthropometry would be lessened if socioeconomic deprivation or segregation were minimised or eliminated.

METHODS

The NICHD Fetal Growth Studies—Singletons was a prospective cohort study that recruited a racially and ethnically diverse sample from 12 US sites between 2009 and 2013. The study has been described in detail previously,[13] but briefly, participants were recruited in the first trimester (8–13 weeks) and followed through delivery. To be consistent with our prior work describing associations between individual socioeconomic factors and neonatal anthropometry,[10] we restricted analyses to the NICHD Fetal Growth Standard cohort (n=1736), which included women at low risk for fetal growth abnormalities, no pregnancy complications or preterm birth and no congenital anomalies.[13] Residential zip codes were obtained at the time of enrolment for 1614 participants and matched to counties using the Department of Housing and Urban Development crosswalk.[14] When zip codes were matched to multiple counties (n=31), the county was assigned according to which had the highest residential ratio (ie, the percentage of residential addresses in a zip code that are located in a given county) and was thus the most likely county of residence.[14] Most of these duplicated matches were assigned to counties with a residential ratio of >90% (n=21), with the remaining 10 assigned to counties with >50% residential ratios (range 59%–86%).

Patient and public involvement

Due to the observational nature of the NICHD Fetal Growth Studies, which was designed to create population-based fetal growth curves, patients and the public were not involved in the design or conduct of the study, nor the choice of outcomes.

Neonatal anthropometry

Birth weight was abstracted from medical records. Neonatal length, head circumference (HC) and abdominal circumference (AC) were obtained by trained study staff within 1–3 days from birth (median=1, IQR 1–2 days), using a standardised protocol (online supplemental materials). All measurements were taken at least two times to the nearest 0.1 cm and averaged.

County-level socioeconomic indicators

County-level indicators were calculated using data from the US Census Bureau's American Community Survey 5-year estimates for the period 2009–2013. The Powell-Wiley Neighborhood Deprivation Index (NDI) is a composite measure used to capture neighbourhood economic disadvantage, and represents an area-level metric of income, poverty and employment status.[15 16] In calculating the NDI, researchers used factor analysis to identify 13 key variables based on prior work.[17 18] The education isolation index represents the likelihood of an individual being proximate, based on residence, to someone with their same level of educational attainment.[19] The education isolation index is a spatial measure, which accounts for encounters that could occur between people in adjacent counties. For our analysis, a high score (1.0) indicates that an individual would interact only with people with less than a bachelor's degree, which could indicate less access to resources or employment.[19]

Because race/ethnic differences in neonatal size may also be influenced by factors other than income, employment or education, we evaluated two measures of racial residential segregation, which have been shown to strongly influence health disparities.[20] Similar to education isolation, the racial isolation index is a spatial measure that describes the likelihood that a person would be proximate, based on residence, to somebody with a different race/ethnicity from their own.[21] For example, for non-Hispanic Black (NHB) individuals, high isolation (1.0) indicates that all individuals living in a county and adjacent areas are NHB, while low isolation (0) indicates maximal proximity to others of a different race/ethnicity, which may indicate higher racial integration or interaction with others from different race/ethnic groups. The Racial Evenness index, or Thiel's H (h-index) describes diversity, or the extent to which race/ethnic groups are evenly distributed in a geographic region.[22] Typically, higher scores indicate a more even distribution, but for consistent interpretation across indicators, scores were reverse-coded so that the lowest score (0) represents an even racial distribution, and the highest score (1.386) represents the most disproportionate distribution. Unlike other measures of segregation, the h-index is designed to account for multiple race/ethnic groups. NDI and education and racial isolation were all calculated using the *ndi* package in R V.4.3.0 (R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org).[23] The h-index was calculated based on the formula provided for a geographic region.[24]

Covariates

Maternal race and ethnicity were self-reported as Asian or Pacific Islander, Hispanic, NHB or non-Hispanic White (NHW) at enrolment. All analyses were adjusted for individual sociodemographic factors, including maternal age, pre-gravid body mass index, parity (nulliparous vs multiparous), education (college degree or higher vs less than college), marital status (married/partnered vs no), insurance status (private vs other) and infant sex. We additionally adjusted for days to neonatal exam for length, HC and AC. All adjustment variables were selected based on a directed acyclic graph (online supplemental figure S1), which was conceptualised based on factors that may influence racial/ethnic disparities in neonatal anthropometry.

Analysis

We calculated the mean and median for each county-level indicator by race/ethnic group. To evaluate overall associations between county-level indicators and neonatal anthropometry, we fit linear mixed models with county-level intercepts to account for clustering between individuals living in the same county. Next, to determine whether race/ethnic differences in neonatal anthropometry varied by indicator, we included an interaction term between race/ethnicity with each selected indicator in each outcome model. Statistical significance for interactions was set at p=0.10. The purpose of including interaction terms in this step was to evaluate whether associations between objective measures of deprivation and segregation and anthropometry varied by race/ethnicity, which influences how controlled direct effects (CDEs) are calculated in causal mediation.[25]

We employed causal mediation techniques to evaluate the extent to which county-level indicators might influence race/ethnic differences. Primarily, we were interested in creating a counterfactual scenario to determine how race/ethnic differences in anthropometry may be influenced by adjusting indicator levels from real-world to minimal levels with the assumption that these would be optimal for growth. Conducting mediation analyses in this manner is useful for evaluating policy interventions on a population-level and relies on the interpretation of the percentage eliminated as opposed to the percentage mediated.[26] Using PROC CAUSALMED in SAS and the *mediation* package in R, and including interaction terms between the exposure (race/ethnicity) and mediator (county-level indicator), we calculated the total effect, which can be interpreted as the association between race/ethnicity and anthropometry without considering the county-level indicator. We calculated two CDEs, which are interpreted as the association between race/ethnicity and anthropometry after accounting for the mediating effects of the county-level indicator. In the first set of models, the actual or 'real-world' CDE was calculated based on the county-level indicator being set to the mean level in the population to assess the extent to which associations between race/ethnicity and anthropometry may be mediated by the indicator based on current levels of deprivation or segregation in the county of residence. In the second set of models, the minimal CDE was calculated by setting the mediator to the lowest possible level in the population. The minimal CDE is interpreted as the difference in neonatal anthropometry that would exist if everyone lived in a county with the lowest possible levels of deprivation or segregation. For example, setting the racial evenness score to 0 would mimic a scenario where everyone lived in a county with an even distribution of race/ethnic groups, or high diversity. The percentage difference in outcomes that could be eliminated was calculated as (Total Effect−$CDE_{minimal}$)/Total Effect×100. Based on the equation, the per cent eliminated may be greater than 100% when there is a sign change between the total effect and the CDE (eg, the total effect is negative and CDE is positive).

In a sensitivity analysis to account for gestational age at delivery and potential variations in neonatal size based on delivery timing, we calculated z-scores (z=(observed−mean)/SD), based on means and SD from within the sample for each anthropometric measure at each week of gestational age at delivery (37–41 weeks, where deliveries that occurred at 42 weeks (n=7) were included in 41-week calculations). We then repeated mediation analyses using z-scores as the outcome. Additionally, we adjusted analyses for annual family income (<\$30 000, 30 000–39 999, \$40 000–49 999, \$50 000–\$74 999, \$75 000–\$99 999, \$100 000 or more, refused to answer, don't know). The 'missing' income categories (refused, don't know) comprised 10.6% of the sample, and may not be immediately interpretable, but income may still be an important confounding variable in the associations examined. All analyses were completed in SAS V.9.4 (Cary, North Carolina, USA) and R V.4.3.

RESULTS

In our sample, 19.6% of women identified as Asian/Pacific Islander, 27.6% as Hispanic, 24.4% as NHB and 28.4% as NHW, with a mean gestational age at delivery of 39.5 weeks. On average, Asian women lived in counties with the highest neighbourhood deprivation, while NHW women lived in counties with the lowest deprivation (figure 1). NHW women tended to live in counties with higher racial isolation (eg, less proximity to or potential interaction with non-NHW residents), and both Hispanic and Asian women lived in counties with more racial evenness relative to NHW and NHB women. Racial/ethnic descriptions of individual socioeconomic characteristics and neonatal anthropometrics in this cohort have been published previously,[10] but generally, for birth weight, length, HC and AC, NHW women had the largest neonates, followed by Hispanic, Asian and NHB women.

Overall associations between county-level factors and neonatal anthropometry are presented in table 1. The coefficients in table 1 represent the associations between county-level indicators and neonatal anthropometry

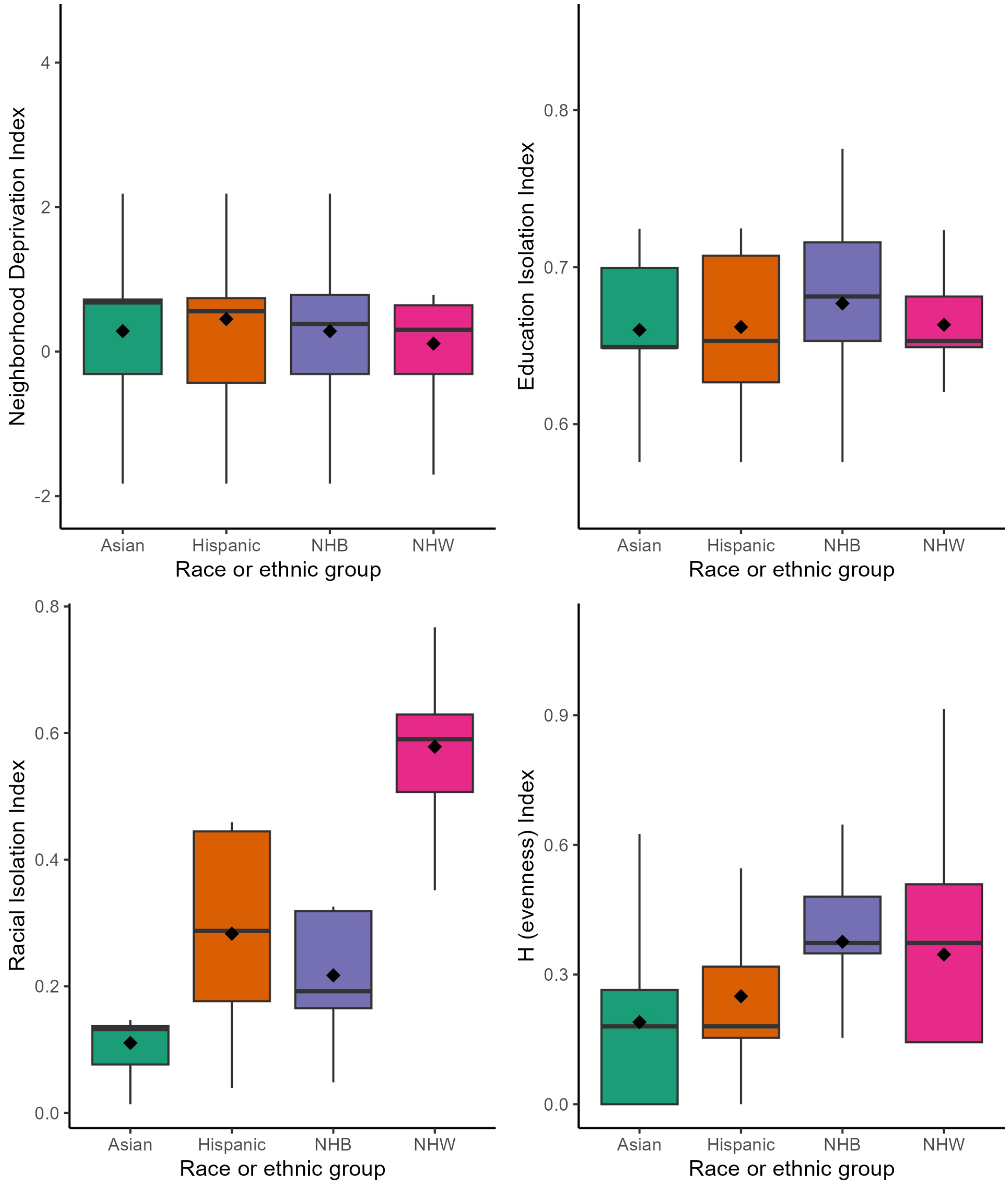

Figure 1 Distribution of county-level indicators by maternal race or ethnic group. Note that h index is reverse-coded in all analyses, such that higher values reflect lower diversity. Lower scores reflect higher diversity. NHB, non-Hispanic Black; NHW, non-Hispanic White.

without accounting for potential differences in associations by maternal race/ethnicity. Annotations in the table indicate where associations between indicators and anthropometry varied by maternal race/ethnicity, identified by significant interaction terms. Specifically, there were significant interactions between race and county-level indicators for associations between racial isolation and evenness for nearly all anthropometric measures, and significant interactions between all indicators and AC.

For results of mediation analyses, when comparing the total effect to the real-world CDE, there were few associations between maternal race/ethnicity and neonatal anthropometry that appeared to be substantially mediated by county-level indicators. However, when county-level indicators were set to their minimal level, CDEs were typically substantially lower than the total effects (table 2, online supplemental tables S1–S3), indicating that differences in neonatal anthropometry would be minimised in a hypothetical setting where indicators of deprivation and segregation were set to levels that indicated high-resource availability and racial/ethnic integration or diversity. For example, in the comparison of Asian versus NHW women, setting racial evenness and education isolation to minimal levels would eliminate 49.3% and 81.8% of differences in birth weight, respectively. Similarly, setting racial evenness to minimal levels (maximum diversity) would eliminate 79.9% of the difference in birth weight

Table 1 Associations between county-level indicators and neonatal anthropometry (β (95% CIs))

County-level SES indicators	Birth weight (g)	Length (cm)	Head circumference (mm)	Abdominal circumference (mm)
Neighbourhood Deprivation Index	−0.10 (−2.4, 2.2)	0.02 (0.00, 0.04)	−0.01 (−0.01, 0.00)	0.00 (−0.01, 0.02)*
Education isolation index (no college degree vs college graduate)	12.7 (−51.1, 76.5)	0.19 (−0.37, 0.74)*	−0.20 (−0.45, 0.04)	−0.32 (−0.76, 0.13)*
Racial isolation index	23.5 (13.3, 33.8)*	0.04 (−0.02, 0.10)	0.07 (0.03, 0.10)*	0.12 (0.07, 0.18)*
Racial evenness, county h index	13.8 (1.8, 25.8)*	−0.01 (−0.13, 0.12)*	−0.01 (−0.06, 0.04)	−0.09 (−0.18, 0.01)*

Note: All models adjusted for days to neonatal exam (except birth weight), maternal age, prepregnancy body mass index, parity, educational attainment, marital status, insurance status and infant sex.
*It indicates significant (p<0.10) interaction between indicator and maternal race/ethnicity, suggesting associations vary by race/ethnic group.
SES, socioeconomic status.

Table 2 County-level mediation results (β (95% CIs)) by maternal race/ethnic group compared with non-Hispanic White, birth weight (g)

County-level socioeconomic indicator	Asian vs NH White			
	Total effect	Overall CDE	Minimal CDE	Percentage eliminated
Neighbourhood Deprivation Index	−145.3 (−205.9, −84.7)	−149.4 (−210.2, −88.6)	−246.5 (−440.6, −52.5)	−69.7
Education isolation index	−146.8 (−207.4, −86.1)	−143.1 (−203.9, −82.4)	−26.7 (−230.0, 176.6)	81.8
Racial isolation index	−147.0 (−207.7, −86.3)	−201.1 (−521.0, 118.7)	124.4 (−107.3, 356.2)	184.6
Racial evenness, h index	−145.3 (−205.8, −84.7)	−118.8 (−184.1, −53.5)	−73.6 (−179.0, 31.9)	49.3
	Hispanic vs NH White			
	Total effect	Overall CDE	Minimal CDE	Percentage eliminated
Neighbourhood Deprivation Index	−84.0 (−160.5, −7.4)	−80.5 (−159.1, −1.8)	−54.9 (−208.2, 98.3)	34.6
Education isolation index	−84.1 (−160.6, −7.6)	−83.3 (−159.6, −6.9)	29.4 (−123.8, 182.6)	135.0
Racial isolation index	−83.1 (−159.5, −6.7)	−43.2 (−146.9, 60.5)	194.5 (−22.8, 411.8)	334.1
Racial evenness, h index	−82.3 (−158.7, −5.9)	−62.6 (−141.6, 16.3)	5.2 (−123.4, 133.8)	106.3
	NH Black vs NH White			
	Total effect	Overall CDE	Minimal CDE	Percentage eliminated
Neighbourhood Deprivation Index	−195.4 (−271.2, −119.7)	−194.9 (−270.8, −119.1)	−162.6 (−347.8, 22.4)	16.8
Education isolation index	−205.4 (−281.2, −129.5)	−205.1 (−280.8, −129.3)	7.0 (−207.1, 221.0)	103.4
Racial isolation index	−205.0 (−280.3, −129.7)	−238.0 (−398.1,−77.9)	80.4 (−135.1, 295.9)	139.2
Racial evenness, h index	−200.5 (−275.5, −125.5)	−199.3 (−274.8, −123.8)	−40.3 (−182.0, 101.3)	79.9

All models adjusted for maternal age, pre-pregnancy BMI, parity, education, marital status, insurance status and infant sex.
BMI, body mass index; CDE, controlled direct effect; NH, non-Hispanic.

between neonates of NHB and NHW women, and all the difference (106.3%) in birth weight between Hispanic and NHW women (table 2). Although most of our findings followed these patterns, there were some contrary results. Setting racial isolation to minimal levels increased birth length differences of neonates between NHW and both Hispanic (−79.2%, online supplemental table S1) and NHB (−104.1%) women, and increased AC differences between Asian (−203.2%, online supplemental table S3) and NHW women. Results of sensitivity analyses using anthropometric z-scores were similar to the main results, with no differences in the overall interpretation of findings (online supplemental tables S4–S7). Interpretation of findings was also similar after adjusting for annual family income, with some results slightly attenuated (online supplemental tables S8–S11).

DISCUSSION

In a large, racially and ethnically diverse cohort of pregnant women at low risk for fetal growth abnormalities, we found that associations between county-level indicators and neonatal anthropometry consistently varied by maternal race or ethnicity, indicating that race/ethnicity is an important consideration in studies evaluating birth size in the context of area-level residential environment. Moreover, using a unique, counterfactual approach to area-level analyses, we found that most maternal race/ethnic differences in neonatal birth weight, length, HC and AC were partially or completely eliminated in a hypothetical setting where county-level indicators of deprivation and segregation were set to minimal levels. Specifically, when neighbourhood deprivation was low, education and racial isolation were low or racial/ethnic groups were equally represented in a county, anthropometric differences decreased substantially when comparing either neonates of Asian, Hispanic or NHB women to neonates of NHW women. Our findings remained when accounting for length of gestation using z-scores, and when adjusting for annual family income.

These findings are well supported by the literature describing increased risk of preterm birth and low birth weight,[5 12] and other adverse adult health outcomes[27] in settings of high neighbourhood deprivation and segregation. To our knowledge, no study has evaluated neighbourhood context as a potential explanation of racial/ethnic differences in individual neonatal anthropometric measures. Such an analysis may provide a more nuanced evaluation of differences in neonatal size than outcomes with dichotomous cut-points, such as low or small-for-gestational age birth weight. Though conclusions cannot be made on direct causality, there are two established models that explain how neighbourhood deprivation and segregation influence health disparities, including disparities in birth size.[28] The materialist model hypothesises that lack of access to material goods, such as quality food and housing, and lack of access to essential services, including medical care and social resources, negatively influence health beyond personal SES.[29] Though a materialist pathway is implicit in neighbourhood deprivation indices, it is also implicated in segregation via historical systems of discrimination that result in racial/ethnic minority groups living in neighbourhoods characterised by poor-quality physical and social environments[20] and higher exposure to environmental pollutants.[30] The psychosocial model describes the formation and perpetuation of health disparities in terms of direct or indirect effects of stress.[28] Specifically, neighbourhood disadvantage has been associated with disruptions in hypothalamic-pituitary-adrenal axis activity via altered patterns of cortisol production and regulation.[31 32] Stress pathways may be activated when individuals are exposed to neighbourhood disadvantage and discrimination associated with segregation, as elucidated in the 'weathering' hypothesis, which describes biological wear and tear associated with racism, social and economic disadvantage and disenfranchisement, as they pertain to disparities in birth outcomes.[33] These disruptions in stress regulation pathways may subsequently slow fetal growth trajectories and contribute to the development of adult morbidities.[34]

Although setting area-level indicators to minimal levels usually resulted in reduced race/ethnic differences in anthropometrics, we found some contrary results. For racial isolation, differences in birth length appeared to increase for neonates of Hispanic and NHB women, and differences in AC appeared to increase for neonates of Asian women compared with NHW. These results could reflect previously reported protective effects of living in ethnic enclaves for both Asian[35] and Hispanic women,[36] where racial isolation could be high. However, considering that all other anthropometric differences, including birth weight differences, decreased when isolation was set to minimal levels, these inconsistent results may also be due to chance. Additionally, for neonates of Asian women only, setting neighbourhood deprivation to 0 was also associated with larger differences in birth weight, HC and AC compared with NHW. Some differential associations have been observed by race/ethnicity between neighbourhood deprivation and risk of preterm birth and low birth weight,[5] though to our knowledge, most studies focus on disparities between NHB and NHW individuals. Some prior work has found no effect of deprivation on neonates of Asian women, and differential effects in NHW women, though these studies are restricted to risk of low birth weight.[5]

Without considering the interaction with race/ethnicity, county-level indicators were not generally associated with differences in neonatal anthropometric measures in our sample. In particular, the minimal NDI appeared to have a less consistent influence on anthropometric differences relative to the other SES indicators. Our results could indicate that NDI is not a sensitive indicator of disadvantage in a healthy population. Due to historical redlining, a legal structure that imposed segregation,[20] neighbourhood disadvantage is a key feature of segregated areas composed of racial/ethnic minority groups.

Thus, segregation indices may capture additional adverse environmental factors that are unmeasured by the NDI in our sample. However, it is important to highlight that no epidemiological study can fully account for the complex interaction between environment, individual and genetic factors. Approximately 15%–22% of differences in birth weight among individuals may be explained by maternal genetic factors.[37] There is also evidence that women of African and Asian ancestry may have a higher number of genetic variants associated with lower birth weight than those of European ancestry, though genetic variants are yet to be validated in diverse ancestral populations.[38] Nevertheless, the social concept of 'race' is distinct from that of ancestry, and the former is specifically associated with differential access to resources and treatment via segregation and discrimination in the USA.[39] Our findings highlight the relevance of structural conditions to birth weight disparities, suggesting that differences in birth size by race/ethnicity are likely influenced by complex interactions among environmental and other factors.[40]

Strengths of our study include a low-risk and racially and ethnically diverse population, which allowed us to evaluate disparities for Asian and Hispanic women in addition to NHB women relative to NHW. Though Black-White disparities are widely researched, we demonstrated that differences in neonatal anthropometry were influenced by county-level socioeconomic and segregation indicators for Asian and Hispanic women as well, who are frequently documented as having similar birth outcomes to NHW women,[41] though it is important to note ancestral heterogeneity in these groups. Furthermore, by limiting our analyses to healthy women with no history of chronic disease, pregnancy complications or preterm deliveries, we eliminated several confounding factors that vary in incidence by race/ethnicity and influence neonatal size, such as preterm birth and hypertensive disorders of pregnancy. By using residential zip codes, we were able to evaluate county of residence vs county of delivery, which may provide a more accurate representation of daily exposure to neighbourhood factors than using delivery hospital as a proxy for residence.

Residential zip code data may also be a limitation of our analysis, as we were unable to analyse all aspects of segregation, including concentration, clustering or centralisation, which would require information by census tract or on the block level to evaluate. However, it has been argued that these operationalisations are all categories of isolation and evenness.[42] Similarly, we were unable to evaluate potential associations with historic redlining, but our consistent results on isolation and evenness indicate that segregation practices may explain some of the race/ethnic differences in neonatal anthropometry observed in our sample. Another limitation is that our residential data were collected in the first trimester, which may be a good proxy for neighbourhood conditions around the time of conception, but we do not have information on earlier residential history. Lifecourse theories emphasise the importance of exposures in the preconception period for the formation of disparities[6 27] and some women may be misclassified on their exposure status to neighbourhood deprivation or segregation. Furthermore, restricting our sample to healthy participants may limit generalisability to other pregnant populations. We anticipate that our findings could be even more pronounced in individuals exposed to more extreme neighbourhood disadvantage and segregation, who may typically experience higher rates of chronic conditions and pregnancy complications.

We did not adjust for all individual factors that may influence birth size, such as diet, physical activity or other behavioural factors. However, individual behaviours are heavily influenced by social and environmental conditions and are typically understood to be intermediary factors in the association between area-level SES and social capital and birth outcomes.[8] Although improvements in birth outcomes may be observed following individual behavioural interventions, lasting population-level change may only be obtained following upstream interventions that promote health equity.[43] Our results provide evidence for potential areas of policy intervention to improve neighbourhood quality and reduce health disparities. However, our findings should be interpreted with caution, as causal mediation analyses can only provide theoretical answers to hypothetical situations.

CONCLUSION

Our findings suggest that, in a hypothetical ideal scenario of no segregation or deprivation, race/ethnic differences in neonatal anthropometry may be substantially reduced or eliminated. Our results also highlight the importance of considering area-level indicators of SES and the interaction of these indicators with race/ethnicity in analyses of disparities.

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Contributors JLG conceived the study, conducted the analyses and drafted and revised all aspects of the manuscript. CL helped to conceptualise the study

and revised the manuscript. ZC helped to conceptualise the data analysis plan, supervised analyses and revised the manuscript. KW contributed to the analytic plan, assisted in data analysis and revised the manuscript. PM and MO coordinated data acquisition, contributed to the analytic plan and reviewed and revised all aspects of the manuscript. WAG and RN were primary investigators on the NICHD Fetal Growth Studies and led original data collection efforts and revised the manuscript. FT-A revised the manuscript and provided subject matter expertise. KG supervised all aspects of the study and revised the manuscript. JLG accepts full responsibility for the finished work and the conduct of the study, had access to the data, controlled the decision to publish and is responsible for the overall content as guarantor.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD) IRB Protocol # 09-CH-N152. Participants gave informed consent to participate in the study before taking part.

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Data availability statement Data are available upon reasonable request. Deidentified data are available upon request. Address inquiries to the corresponding author for more information.

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