JAMA Pediatrics | Original Investigation

Childhood Asthma Incidence, Early and Persistent Wheeze, and Neighborhood Socioeconomic Factors in the ECHO/CREW Consortium

Antonella Zanobetti, PhD; Patrick H. Ryan, PhD; Brent Coull, PhD; Cole Brokamp, PhD; Soma Datta, MS, MBA; Jeffrey Blossom, MA; Nathan Lothrop, PhD; Rachel L. Miller, MD; Paloma I. Beamer, PhD; Cynthia M. Visness, PhD, MPH; Howard Andrews, PhD; Leonard B. Bacharier, MD; Tina Hartert, MD; Christine C. Johnson, PhD; Dennis Ownby, MD; Gurjit K. Khurana Hershey, MD, PhD; Christine Joseph, PhD; Song Yiqiang, PhD; Eneida A. Mendonça, MD, PhD; Daniel J. Jackson, MD; Heike Luttmann-Gibson, PhD; Edward M. Zoratti, MD; Anne L. Wright, PhD; Fernando D. Martinez, MD; Christine M. Seroogy, MD; James E. Gern, MD; Diane R. Gold, MD; for the Children's Respiratory and Environmental Workgroup (CREW) Consortium

IMPORTANCE In the United States, Black and Hispanic children have higher rates of asthma and asthma-related morbidity compared with White children and disproportionately reside in communities with economic deprivation.

OBJECTIVE To determine the extent to which neighborhood-level socioeconomic indicators explain racial and ethnic disparities in childhood wheezing and asthma.

DESIGN, SETTING, AND PARTICIPANTS The study population comprised children in birth cohorts located throughout the United States that are part of the Children's Respiratory and Environmental Workgroup consortium. Cox proportional hazard models were used to estimate hazard ratios (HRs) of asthma incidence, and logistic regression was used to estimate odds ratios of early and persistent wheeze prevalence accounting for mother's education, parental asthma, smoking during pregnancy, child's race and ethnicity, sex, and region and decade of birth.

EXPOSURES Neighborhood-level socioeconomic indicators defined by US census tracts calculated as *z* scores for multiple tract-level variables relative to the US average linked to participants' birth record address and decade of birth. The parent or caregiver reported the child's race and ethnicity.

MAIN OUTCOMES AND MEASURES Prevalence of early and persistent childhood wheeze and asthma incidence.

RESULTS Of 5809 children, 46% reported wheezing before age 2 years, and 26% reported persistent wheeze through age 11 years. Asthma prevalence by age 11 years varied by cohort, with an overall median prevalence of 25%. Black children (HR, 1.47; 95% CI, 1.26-1.73) and Hispanic children (HR, 1.29; 95% CI, 1.09-1.53) were at significantly increased risk for asthma incidence compared with White children, with onset occurring earlier in childhood. Children born in tracts with a greater proportion of low-income households, population density, and poverty had increased asthma incidence. Results for early and persistent wheeze were similar. In effect modification analysis, census variables did not significantly modify the association between race and ethnicity and risk for asthma incidence; Black and Hispanic children remained at higher risk for asthma compared with White children across census tracts socioeconomic levels.

CONCLUSIONS AND RELEVANCE Adjusting for individual-level characteristics, we observed neighborhood socioeconomic disparities in childhood wheeze and asthma. Black and Hispanic children had more asthma in neighborhoods of all income levels. Neighborhood- and individual-level characteristics and their root causes should be considered as sources of respiratory health inequities.

Editorial page 739

Supplemental content

Author Affiliations: Author affiliations are listed at the end of this article.

Group Information: A complete list of the members of the Children's Respiratory and Environmental Workgroup (CREW) Consortium appears in Supplement 2.

Corresponding Author: Antonella Zanobetti, PhD, Department of Environmental Health, Harvard T.H. Chan School of Public Health, 401 Park Dr, Boston, MA 02215 (azanobet@hsph.harvard.edu).

JAMA Pediatr. 2022;176(8):759-767. doi:10.1001/jamapediatrics.2022.1446
Published online May 23, 2022. Corrected on August 1, 2022.

Wheezing during early childhood is common and frequently incited by viral respiratory illnesses.[1,2] While childhood wheezing may remit, symptoms persist in subgroups of children, many of whom have allergic sensitization and lower lung function and continue on to develop asthma.[1,2] In the United States, asthma remains the most common chronic disease of childhood. The prevalence and morbidity of asthma are disproportionately borne by Black and Hispanic children.[3] Moreover, the prevalence and morbidity of childhood asthma are significantly elevated in neighborhoods with increased poverty and urbanicity.[3-5] Understanding the relationships between race and ethnicity and the physical and social environments of neighborhoods that contribute to the persistence of early childhood wheeze and onset of asthma is essential to guiding research, policies, and interventions to reduce asthma disparities.

Recently, childhood asthma incidence rates in the United States were examined among birth cohorts participating in the Environmental Influences on Child Health Outcomes (ECHO)[6] and Children's Respiratory and Environmental Workgroup (CREW)[7] consortiums, and differential rates of asthma incidence were identified by age, sex, race, and calendar years. Asthma incidence rates were highest among children younger than 4 years and Black and Caribbean Hispanic children. The contribution of neighborhood-level factors to asthma incidence in these populations was not examined. The objectives of the present analysis are to (1) determine the associations of neighborhood-level socioeconomic status measures with early and persistent childhood wheezing and asthma incidence and (2) examine whether neighborhood-level socioeconomic status modifies the association between race and ethnicity and childhood wheezing and asthma incidence.

Key Points

Question Is there an association between neighborhood characteristics at birth, race and ethnicity, and the risk for developing childhood wheeze and asthma?

Findings In this cohort study, using survival analysis, we found that children born in census tracts with higher population density and greater proportion of low-income households and poverty had higher hazard ratios of asthma incidence, after adjusting for individual-level characteristics. Black and Hispanic children were at significantly higher risk for developing asthma than White children, and they remained at increased risk for asthma incidence when we examined the risk for asthma across neighborhoods of all income levels.

Meaning Neighborhood characteristics at birth and race and ethnicity play a role in the development of childhood wheezing and asthma; strategies to reduce asthma disparities must consider the multilevel factors that underlie these findings, including structural and social determinants of health.

Methods

Study Population

Our study population included 10 of 12 birth cohorts participating in CREW (eTable 1 in Supplement 1). Eligibility criteria, study recruitment, and other methods have been described.[8] All cohorts had institutional review board approvals from each participating cohort's institution, and participants provided written informed consent.

Neighborhood Socioeconomic Factors

We ascertained census tract-level information for all CREW participants at their birth address using our previously described Decentralized Geomarker Assessment for Multi-site Studies (DeGAUSS) approach.[9] Briefly, US Census data including population density (population per kilometer squared), median household income, percentage below poverty level (percentage of individuals in tract whose income is below the federal poverty level), percentage of low-income households (income <$7500, $12 500, $20 000, and $25 000 for census years 1980, 1990, 2000, and 2010, respectively), percentage without high school diploma, percentage occupied housing, median gross rent, median housing value, percentage with a female head of household, percentage with a single-parent head of household, and percentage unemployed. Boundary files for the years 1980, 1990, 2000, and 2010 were provided along with R code in a Docker container to each cohort.[9] Cohort data managers merged census data to participant birth address using census year nearest to the birth year and then removed identifiable information.

For our analyses, enabling comparisons across all US census tracts, we standardized each census variable by calculating the z score by subtracting the mean of all tract values in the United States from the value for the participant's tract and dividing this result by the standard deviation of all tract values in the US Census data. We used continuous z scores in our main analyses, while for effect modification analysis, z score variables were categorized into quartiles: low for z scores less than the 25th percentile, medium for z scores in the 25th through 75th percentiles, and high for z scores greater than the 75th percentile.

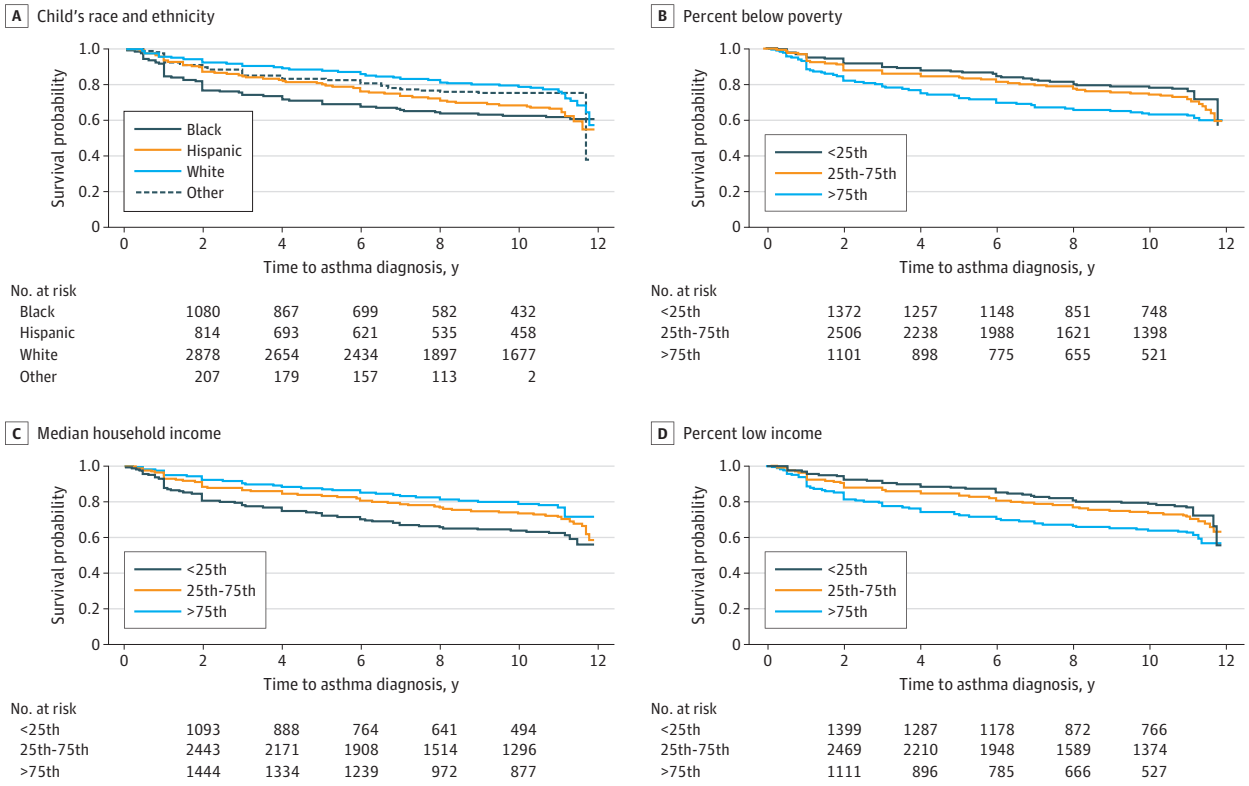
Health Outcomes

We examined asthma incidence through age 11 years, early wheeze, and persistent wheeze. Age at asthma onset was ascertained by caregiver report of the age at which a doctor diagnosed their child with asthma, up to age 11 years. In a secondary definition, we excluded cases of incident asthma if children were reported to have asthma before age 5 years without any reported wheeze from ages 5 through 11 years. We defined early wheeze as caregiver-reported wheeze at either age 1 or 2 years and persistent wheeze as any report of wheeze up to age 4 years and at least 1 report of wheeze from ages 5 through 11 years.

Individual Characteristics

Cohort data managers provided data collected at enrollment, including child's sex, child's race and ethnicity (as reported by parent or caregiver), mother's education, maternal-reported smoking during pregnancy, and parental history of asthma. We classified child's race and ethnicity as Hispanic, non-Hispanic Black (Black), non-Hispanic White (White), and other

Figure 1. Kaplan-Meier Curves for Child's Race and Ethnicity and for Census Characteristics



(for any race or ethnicity that did not fit into the preceding categories). The Hispanic category included specific Hispanic origins: Hispanic Mexican, Hispanic Puerto Rican/Dominican, and Hispanic of other or unknown regional origins. Mother's education was categorized as (1) less than high school diploma, (2) high school diploma, and (3) some college, associate/technical degree, bachelor's, master's, or doctoral degree. Parental history of asthma was dichotomized as any parental history (history in the mother, father, or both) vs no parental history. Self-reported household income was collected for all cohorts except the Childhood Allergy and Asthma Study and categorized as $30 000 or less, $30 000 to $80 000, and $80 000 or more. In addition, we categorized participants' decade of birth (1980-1989, 1990-1999, 2000-2009, 2010-2020) and geographic region as Northeast (Baltimore, Maryland; Boston, Massachusetts; New York City, New York), Midwest (Detroit, Michigan; Cincinnati, Ohio; Madison, Wisconsin; and St Louis, Missouri), and Southwest (Tucson, Arizona).

Statistical Analyses

Asthma Incidence

We applied Kaplan-Meier[10] curves to evaluate the association of child's race and ethnicity and census variables with age at asthma onset, without adjusting for confounding variables. We applied Cox proportional hazard models[11] with a sex stratification of baseline hazard to estimate the association between individual census variables and asthma incidence, adjusting for decade of birth, geographic region, and parental history of asthma (model 1) and adding child's race and ethnicity, mother's education, and smoking during pregnancy in model 2.

Early and Persistent Wheeze

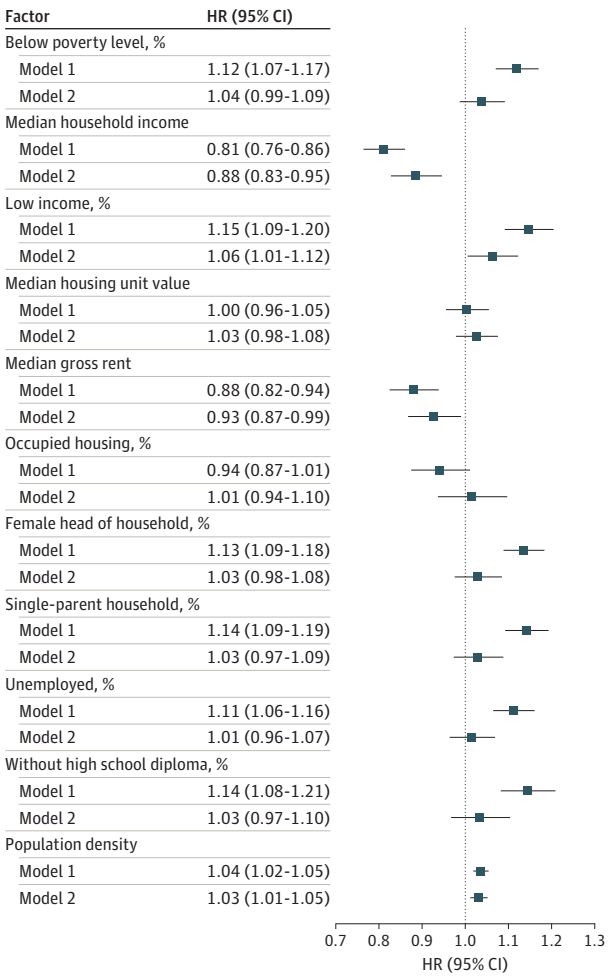
We applied logistic models to estimate the association between each census variable and the outcomes with the same adjustment in models 1 and 2 as for asthma incidence. For all outcomes and models we included 1 census variable at a time.

Effect Modification

We examined whether the association between child's race and ethnicity and each health outcome was modified by neighborhood factors by including in model 2 an interaction term between each categorized tract variable (low, medium, and high) and child's race and ethnicity, thus estimating the hazard ratio (HR) and odds ratio (OR) for Black and Hispanic children compared with White children within each tract-level variable category.

We performed multiple sensitivity analyses by (1) including household income in model 2; (2) conducting the Cox model using the stricter definition of asthma; (3) repeating all analyses stratified by sex; (4) including child's race and ethnicity with specific Hispanic origin[6,7]; and (5) applying the Aalen additive hazard model,[12-14] which estimates the hazard difference or the absolute difference from baseline. This model allowed us to examine effect modification on the additive scale, there-

Figure 2. Hazard Ratios of Asthma Incidence for 1-*z* Score Increase in Census Tract–Level Socioeconomic Factors



Model 1: logistic model adjusting for child's sex, decade of birth, geographic region, and parental history of asthma. Model 2: model 1 plus adjustment for child's race and ethnicity, mother's education, and smoking during pregnancy.

fore accounting for potential differences in baseline risks between subgroups.

Results are presented as HR for asthma incidence and OR for early and persistent wheeze and 95% CI related to 1-*z* score increase in each census variable. eTable 4 in Supplement 1 provides the mean and SD for each census variable by decade to enable conversion of 1-*z* score changes. All analyses were performed in R version 3.404.

Results

Of the 6893 children enrolled in CREW cohorts, our analysis of asthma incidence included 5809 children with a total of 43 260 person-years. Analyses of early wheeze and persistent wheeze included 5686 and 4789 participants, respectively. A diagram of the initial and analytic data sets for each outcome is provided in eFigure 1 in Supplement 1. Covariate data were available for 95% or more of the participants with available outcome data (eFigure 1 in Supplement 1). The overall prevalence of early wheeze was 45.5% and exceeded both the prevalence of persistent wheeze and incident asthma (25.8% and 24.8%, respectively). The prevalence of all outcomes varied across cohorts, which included both population-based and high-risk families based on parental history of asthma (eTable 1 in Supplement 1).[8]

The distribution of individual characteristics demonstrates the racial and socioeconomic diversity among participants and across cohorts (eTables 2 and 3 in Supplement 1). CREW cohorts were 25.5% Black, 17.3% Hispanic, 53.2% White, and 4% other races and ethnicities. Maternal education varied by cohort: more than 90% of participants in the cohorts Childhood Origins of Asthma Study, Wisconsin Infant Study, and Epidemiology of Home Allergens and Asthma Study had a college and/or graduate degree, while 53% to 63% of participants in the Urban Environment and Childhood Asthma cohorts had no high school diploma. The prevalence (range) of maternal smoking during pregnancy and parental history of asthma were 11.7% (1.9%-21.3%) and 33.6% (13.5%-76.7%), respectively. Similar variability has been previously shown in the census factors across all cohorts.[9]

eFigure 2 in Supplement 1 shows the distribution of child's race and ethnicity by categories of neighborhood characteristics. In tracts with low proportions of the population below the poverty level, 83% of the children were White; in tracts with high proportions of the population below the poverty level, 49% of the children were Black and 35% Hispanic, while only 13% were White. Similar racial and ethnic disparities were observed for percentage with low income, population density, and median household income.

Asthma Incidence

The Kaplan-Meier survival curves demonstrate earlier asthma onset among children living in census tracts with higher rates of poverty, lower income, and lower median household income and among Black children (**Figure 1**). Survival curves were similar for medium and low rates of these census variables. We observed significant associations between census variables and asthma incidence, though results were attenuated after adjusting for individual-level covariates (**Figure 2** and eFigure 3 in Supplement 1). Using model 2, significant inverse associations were observed between increased median household income (HR, 0.88; 95% CI, 0.83-0.95) and median gross rent (HR, 0.93; 95% CI, 0.87-0.99) (**Table**). In addition, significant positive associations remained between increased rates of low-income households (HR, 1.06; 95% CI, 1.01-1.12 in model 2 for 1-*z* score increase, corresponding to an approximate 15% increase in low-income households) and increasing population density (HR, 1.03; 95% CI, 1.01-1.05). Mean and SD for each census variable and year are provided in eTable 4 in Supplement 1.

We observed a persistent significant and elevated HR of asthma incidence among Black and Hispanic children compared with White children and in children with parents with history of asthma (Table). Similar elevated HR were found when adjusting for census variables (eTable 5 in Supplement 1).

Table. Hazard Ratios of Asthma Incidence and Odds Ratios of Persistent Wheeze and Early Wheeze for the Individual Characteristics and Census Variables in Model 2[a]

Characteristic	Asthma incidence, HR (95% CI)	OR (95% CI)	
		Persistent wheeze	Early wheeze
Child race and ethnicity[b]			
Black	1.47 (1.26-1.73)	1.76 (1.42-2.17)	1.16 (0.98-1.37)
Hispanic	1.29 (1.09-1.53)	1.38 (1.11-1.72)	1.20 (1.00-1.43)
White	1 [Reference]	1 [Reference]	1 [Reference]
Other	0.98 (0.73-1.30)	1.39 (0.99-1.95)	1.02 (0.77-1.34)
Mother's education			
Some college or more	1 [Reference]	1 [Reference]	1 [Reference]
High school diploma	1.07 (0.93-1.22)	1.08 (0.90-1.29)	1.26 (1.10-1.46)
No high school diploma	1.08 (0.92-1.28)	1.00 (0.79-1.27)	1.42 (1.17-1.72)
Parental history of asthma	2.08 (1.87-2.31)	2.24 (1.95-2.58)	1.64 (1.47-1.85)
Smoking during pregnancy	1.07 (0.91-1.26)	1.32 (1.07-1.63)	1.29 (1.09-1.54)
Census variables from single exposure models			
Median household income	0.88 (0.83-0.95)	0.89 (0.81-0.96)	0.94 (0.88-1.01)
% Below poverty level	1.04 (0.99-1.09)	1.00 (0.93-1.07)	1.00 (0.94-1.05)
% Low income	1.06 (1.01-1.12)	1.02 (0.95-1.10)	1.00 (0.94-1.06)
Median housing unit value	1.03 (0.98-1.08)	0.98 (0.91-1.05)	0.99 (0.94-1.05)
Median gross rent	0.93 (0.87-0.99)	1.02 (0.94-1.11)	0.95 (0.89-1.02)
% Occupied housing	1.01 (0.94-1.10)	0.96 (0.87-1.07)	0.96 (0.89-1.05)
% Female head of household	1.03 (0.98-1.08)	1.07 (0.99-1.15)	1.05 (0.99-1.11)
% Single-parent household	1.03 (0.97-1.09)	1.08 (1.00-1.16)	1.05 (0.98-1.11)
% Unemployed	1.01 (0.96-1.07)	1.05 (0.97-1.13)	0.99 (0.93-1.05)
% Without high school diploma	1.03 (0.97-1.10)	1.04 (0.95-1.13)	1.01 (0.94-1.09)
Population density	1.03 (1.01-1.05)	1.00 (0.97-1.03)	0.98 (0.96-1.01)

Abbreviations: HR, hazard ratio; OR, odds ratio.

[a] Adjusted for decade of birth, geographic region, child's sex, child's race and ethnicity, mother's education, smoking during pregnancy, and parental history of asthma.

[b] Race and ethnicity were reported by each child's parent or caregiver and classified by us as Hispanic, non-Hispanic Black (Black), non-Hispanic White (White), or other (for any race or ethnicity that did not fit into the preceding categories).

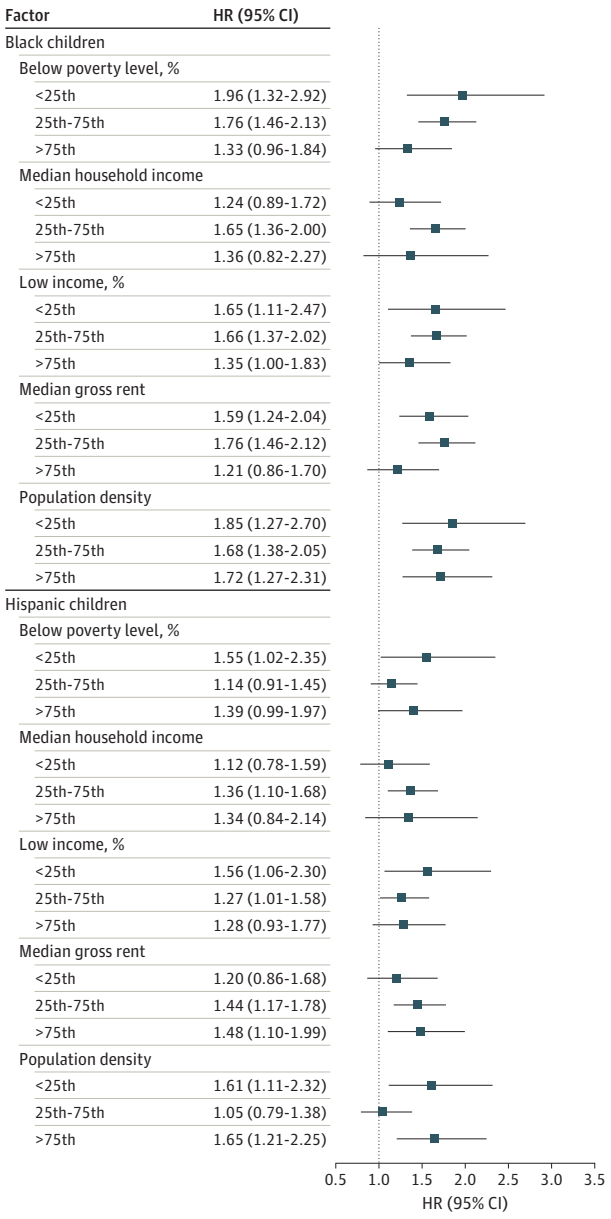
In effect modification analyses, the interaction between child's race and ethnicity and census variables was not statistically significant, and the risk for asthma incidence was elevated for Black and Hispanic children, compared with White children, in all census tracts, though approximately 7% and 20% of the population in tracts with low and medium *z* scores for low income, population density, and poverty was Black (**Figure 3** and eFigures 2 and 4 in Supplement 1). Black children living in census tracts with *z* scores in the 75th percentile or lower for these variables had higher risk of developing asthma compared with White children residing in these same census tracts, after adjusting for covariates. Similar patterns were observed for Black and Hispanic children residing in census tracts with other tract-level indicators (eFigure 4 in Supplement 1). In sensitivity analyses, applying additive hazard models, we did not observe significant effect modification between child race and ethnicity and neighborhood socioeconomic factors, with similar patterns of elevated risk for Black and Hispanic children (eFigure 5 in Supplement 1). We also found that the results did not change and were consistent when we used the secondary asthma incidence definition, additionally adjusted for household income, and used specific Hispanic origin with all Hispanic groups at increased risk of asthma incidence (eFigures 6 and 7 and eTable 6 in Supplement 1). Similar results for both boys and girls were observed for models stratified by sex (eFigure 7 in Supplement 1).

Early and Persistent Wheeze

Most neighborhood socioeconomic factors were associated with both early and persistent wheeze in unadjusted and minimally adjusted model 1 (eFigure 8 in Supplement 1 and **Figure 4**). After adjusting for individual-level covariates (model 2), residing in a census tract with higher median household income remained significantly associated with decreased risk of early wheeze (OR, 0.94; 95% CI, 0.88-1.01, per *z* score increase). For persistent wheeze, in model 2, we observed significantly decreased odds for children residing in census tracts with higher median household income (OR, 0.89; 95% CI, 0.81-0.96) and elevated but not statistically significant odds ratios for census tracts with higher percentage of population with a female head household (OR, 1.07; 95% CI, 0.99-1.15) or single-parent household (OR, 1.08; 95% CI, 1.00-1.16) (Table).

We observed significantly higher odds ratios for both persistent and early wheeze among Black and Hispanic children compared with White children, in children of parents with a history of asthma and among children of mothers who smoked during pregnancy (Table). In models examining the interaction between race and ethnicity and socioeconomic status indicators, we did not observe significant effect modification (results not shown). Additional adjustment for household income and Hispanic region of origin in sensitivity analyses did not change the overall results of our models (results not shown),

Figure 3. Effect Modification of Individual Race and Ethnicity by Selected Neighborhood Socioeconomic Factors



Results are presented as hazard ratios of asthma incidence for Black and Hispanic race and ethnicity compared with White as reference, for each neighborhood socioeconomic factor category.

and all Hispanic groups were at increased risk (eTable 5 in Supplement 1).

Discussion

Black US populations continue to experience nearly 40% higher rates of asthma and 5 times higher rates of asthma-related emergency department visits than White patients with asthma.[15] Despite decades of research, the structural, social, behavioral, and biological determinants that drive these inequitable outcomes remain ill-defined, due in part to the highly correlated nature of race and ethnicity, poverty, adverse physical environments, unequal access to health care, and multitude of structural, systemic, and institutional determinants that are deeply ingrained in US policies and culture.[15] In this longitudinal study of more than 5000 children born over nearly 4 decades, we analyzed the association between race and ethnicity, in the context of neighborhood-level factors, and childhood wheeze and incident asthma. We found large disparities in census socioeconomic indicators by race and ethnicity, with Black and Hispanic children more likely to reside in neighborhoods with greater population densities and higher rates of poverty. We also observed that children born in census tracts with higher levels of poverty and lower household income were at elevated risk for childhood wheezing and developing asthma. Furthermore, race and ethnicity persisted as a risk factor after adjusting for neighborhood income, suggesting the presence of structural inequities that increase wheeze and asthma risk among Black and Hispanic children residing in more affluent as well as poorer neighborhoods.

Efforts to define root causes of asthma-related health disparities among racial and ethnic groups and between urban and rural areas[7,16-18] have been limited by complex interactions among multiple individual- and neighborhood-level factors that contribute to asthma incidence and morbidity.[19-21] Proposing a framework to conceptualize root causes of asthma disparities, the Asthma and Allergy Foundation of America concluded that structural and social determinants, including racism, discrimination, discriminatory policies, education, physical environment, and access to health care play significant roles, with biological and behavioral determinants contributing to a lesser extent.[15] This conclusion applies to individual-level characteristics as well as neighborhood-level descriptors of income and poverty, likely indicators for structural disparities resulting from a lack of resources in less affluent neighborhoods.

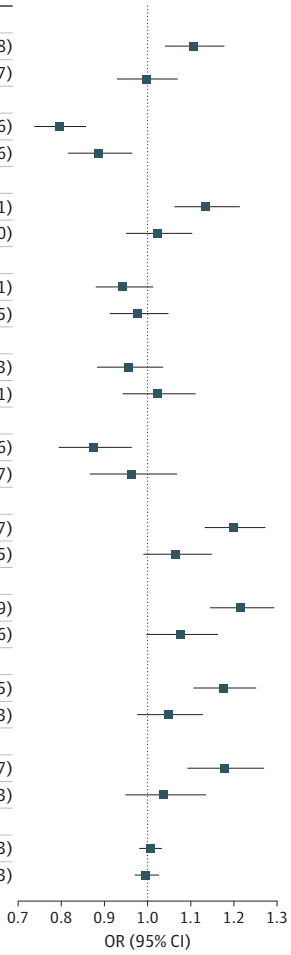
Our findings that both race and ethnicity and neighborhood factors are associated with childhood wheeze and asthma incidence are similar to some but not all prior cross-sectional studies.[3,5] We did not find that neighborhood factors significantly modified estimates of risk for asthma among Black or Hispanic children. However, the risk for asthma incidence remained higher for Black and Hispanic children across neighborhood socioeconomic status categories. Thus, living in more affluent neighborhoods may not remove all of the risk specific to being Black or Hispanic. Stress, racial bias, and differential access to health care and other resources may persist among Black families living in more affluent neighborhoods[22,23] and could contribute to asthma risk.

Our study has multiple strengths, including the prospectively assessed childhood wheeze and asthma from birth through childhood. CREW cohorts are located in urban and rural areas throughout the United States and were enrolled from the 1980s through 2018, providing socioeconomic, racial and ethnic, geographic, and temporal diversity. Another strength was our use of a longitudinal data set of census-derived tract-level socioeconomic, demographic, and housing variables for

Figure 4. Odds Ratios of Persistent Wheeze and Early Wheeze for 1-*z* Score Increase in Each Neighborhood Socioeconomic Factor

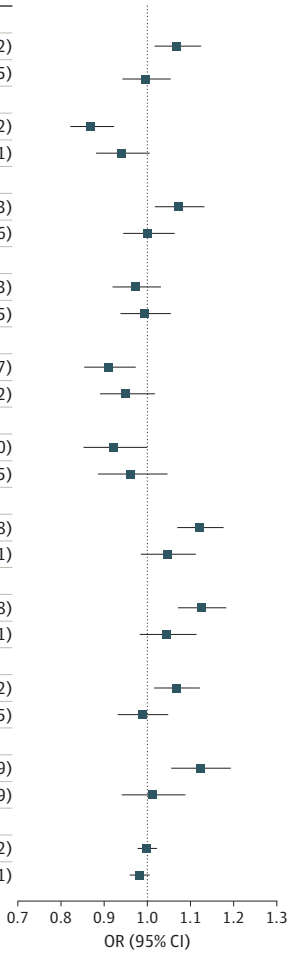
A Persistent wheeze

Factor	OR (95% CI)
Below poverty level, %	
Model 1	1.11 (1.04-1.18)
Model 2	1.00 (0.93-1.07)
Median household income	
Model 1	0.79 (0.74-0.86)
Model 2	0.89 (0.81-0.96)
Low income, %	
Model 1	1.13 (1.06-1.21)
Model 2	1.02 (0.95-1.10)
Median housing unit value	
Model 1	0.94 (0.88-1.01)
Model 2	0.98 (0.91-1.05)
Median gross rent	
Model 1	0.96 (0.88-1.03)
Model 2	1.02 (0.94-1.11)
Occupied housing, %	
Model 1	0.87 (0.79-0.96)
Model 2	0.96 (0.87-1.07)
Female head of household, %	
Model 1	1.20 (1.13-1.27)
Model 2	1.07 (0.99-1.15)
Single-parent household, %	
Model 1	1.22 (1.14-1.29)
Model 2	1.08 (1.00-1.16)
Unemployed, %	
Model 1	1.18 (1.11-1.25)
Model 2	1.05 (0.97-1.13)
Without high school diploma, %	
Model 1	1.18 (1.09-1.27)
Model 2	1.04 (0.95-1.13)
Population density	
Model 1	1.01 (0.98-1.03)
Model 2	1.00 (0.97-1.03)



B Early wheeze

Factor	OR (95% CI)
Below poverty level, %	
Model 1	1.07 (1.02-1.12)
Model 2	1.00 (0.94-1.05)
Median household income	
Model 1	0.87 (0.82-0.92)
Model 2	0.94 (0.88-1.01)
Low income, %	
Model 1	1.07 (1.02-1.13)
Model 2	1.00 (0.94-1.06)
Median housing unit value	
Model 1	0.97 (0.92-1.03)
Model 2	0.99 (0.94-1.05)
Median gross rent	
Model 1	0.91 (0.85-0.97)
Model 2	0.95 (0.89-1.02)
Occupied housing, %	
Model 1	0.92 (0.85-1.00)
Model 2	0.96 (0.89-1.05)
Female head of household, %	
Model 1	1.12 (1.07-1.18)
Model 2	1.05 (0.99-1.11)
Single-parent household, %	
Model 1	1.13 (1.07-1.18)
Model 2	1.05 (0.98-1.11)
Unemployed, %	
Model 1	1.07 (1.02-1.12)
Model 2	0.99 (0.93-1.05)
Without high school diploma, %	
Model 1	1.12 (1.06-1.19)
Model 2	1.01 (0.94-1.09)
Population density	
Model 1	1.00 (0.98-1.02)
Model 2	0.98 (0.96-1.01)



Model 1: logistic model adjusting for child's sex, decade of birth, geographic region, and parental history of asthma. Model 2: model 1 plus adjustment for child's race and ethnicity, mother's education, and smoking during pregnancy.

multiple decades with attention to longitudinal comparability of income, poverty, and geographic boundaries.[9] Our DeGAUSS approach enabled cohort data managers to assign census information to birth record addresses in a decentralized manner, preserving protections for the participants.

Limitations

Study limitations include harmonization of data from several independent cohorts using some different variable definitions. Individual-level income was not available in all cohorts and was coded differently in each cohort. Nevertheless, in sensitivity analyses, our results were consistent in models including individual-level income. Differences in eligibility criteria between cohorts resulted in some cohorts having study populations at increased risk for asthma, when enrollment criteria included parental history of asthma or allergy. We adjusted for parental history of asthma to account for some of these differences. Results were also similar when including a random effect for cohort in our analyses (data not shown). Although we studied neighborhood characteristics at birth, future analyses will also consider how residential mobility may influence changes in neighborhood exposures and how these, in turn, may alter asthma-related outcomes. Nevertheless, our analyses underscore the importance of the environment during early life in asthma development.

Our findings call for further identification of exposures within and across neighborhoods conferring increased risk for Black and Hispanic children and mechanistic studies to ascertain the etiology of this risk. Multiple structural and social determinants of health may play a role in the elevated risk for asthma among Black and Hispanic children, including systemic and individual racism, segregation, poverty, and health care access. Physical environmental factors (eg, indoor and outdoor air pollutants, housing quality, limited greenspace access) may also contribute to asthma incidence and morbidity and are experienced disproportionately by people from racial and ethnic minorities.

Conclusions

Using the information provided by longitudinal CREW cohorts, we found that neighborhood characteristics at birth, including higher population density and poverty, were associated with elevated risk of asthma incidence but did not significantly modify the association between race and ethnicity and asthma incidence. Across all neighborhoods, Black and Hispanic children were at higher risk than White children for developing asthma. Our findings add to the body of knowledge by demonstrating that both race and ethnicity and neighborhood factors are associated with the onset of disease. Future studies should consider neighborhood- and individual-level characteristics that individually or in combination explain elevated rates of asthma incidence. Observational studies identifying multilevel risk factors responsible for inequities in respiratory health can be used to guide interventions and policies enacted at local levels to improve health among those disproportionately exposed to and affected by the environments in which they live.

ARTICLE INFORMATION

Accepted for Publication: December 10, 2021.

Published Online: May 23, 2022. doi:10.1001/jamapediatrics.2022.1446

Correction: This article was corrected on August 1, 2022, to fix the credentials and spelling of the 19th author's name.

Author Affiliations: Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, Massachusetts (Zanobetti, Luttmann-Gibson, Gold); Department of Pediatrics, University of Cincinnati, College of Medicine, Cincinnati, Ohio (Ryan, Brokamp); Division of Biostatistics and Epidemiology, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio (Ryan, Brokamp); Department of Biostatistics, Harvard T.H. Chan School of Public Health, Boston, Massachusetts (Coull); Channing Division of Network Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts (Datta, Gold); Center for Geographic Analysis, Harvard University, Cambridge, Massachusetts (Blossom); Asthma and Airways Disease Research Center, University of Arizona, Tucson (Lothrop, Beamer, Wright, Martinez); Department of Community, Environment, and Policy, Mel and Enic Zuckerman College of Public Health, University of Arizona, Tucson (Lothrop, Beamer); Division of Clinical Immunology, Icahn School of Medicine at Mount Sinai, New York, New York (Miller); Rho, Inc, Chapel Hill, North Carolina (Visness); Department of Biostatistics, Mailman School of Public Health, Columbia University, New York, New York (Andrews); Division of Pediatric Allergy, Immunology, and Pulmonary Medicine, Monroe Carell Jr Children's Hospital at Vanderbilt, Nashville, Tennessee (Bacharier); Division of Allergy, Pulmonary, and Critical Care Medicine, Vanderbilt University School of Medicine, Nashville, Tennessee (Hartert); Department of Public Health Sciences, Henry Ford Health System, Detroit, Michigan (Johnson, Joseph); Division of Allergy and Immunology, Augusta University, Augusta, Georgia (Ownby); Cincinnati Children's Hospital, Division of Asthma Research, Cincinnati, Ohio (Khurana Hershey); Indiana University School of Medicine, Bloomington (Yiqiang); Department of Pediatrics, Indiana University, Bloomington (Mendonça); Department of Pediatrics, University of Wisconsin School of Medicine and Public Health, Madison (Jackson, Seroogy); Department of Medicine, Henry Ford Health System, Detroit, Michigan (Zoratti, Gern); Division of Pulmonary and Sleep Medicine, Department of Pediatrics, College of Medicine, University of Arizona, Tucson (Wright, Martinez).

Author Contributions: Drs Zanobetti and Ryan had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Drs Zanobetti and Ryan are co–first authors.
Concept and design: Zanobetti, Ryan, Coull, Miller, Andrews, Johnson, Khurana Hershey, Joseph, Gold.
Acquisition, analysis, or interpretation of data: Zanobetti, Ryan, Coull, Brokamp, Datta, Blossom, Lothrop, Miller, Beamer, Visness, Andrews, Bacharier, Hartert, Johnson, Ownby, Khurana Hershey, Yiqiang, Mendonça, Jackson, Luttmann-Gibson, Zoratti, Wright, Martinez, Seroogy, Gern, Gold.
Drafting of the manuscript: Zanobetti, Ryan, Datta, Blossom, Joseph, Khurana Hershey, Gold.
Critical revision of the manuscript for important intellectual content: Ryan, Coull, Brokamp, Datta, Lothrop, Miller, Beamer, Visness, Andrews, Hartert, Johnson, Bacharier, Ownby, Khurana Hershey, Yiqiang, Mendonça, Jackson, Luttmann-Gibson, Zoratti, Wright, Martinez, Seroogy, Gern.
Statistical analysis: Zanobetti, Ryan, Coull, Datta, Yiqiang, Luttmann-Gibson.
Obtained funding: Miller, Hartert, Johnson, Khurana Hershey, Zoratti, Seroogy, Jackson, Gern, Gold.
Administrative, technical, or material support: Ryan, Datta, Blossom, Lothrop, Miller, Beamer, Visness, Andrews, Ownby, Khurana Hershey, Mendonça, Luttmann-Gibson, Seroogy, Gern.
Supervision: Coull, Johnson, Khurana Hershey, Joseph, Gern.

Conflict of Interest Disclosures: Dr Zanobetti reported grants from National Institutes of Health (NIH) during the conduct of the study and grants from National Institute on Aging outside the submitted work. Drs Ryan, Coull, and Miller reported grants from NIH during the conduct of the study. Dr Beamer reported grants from NIH during the conduct of the study and grants from NIH and the Environmental Protection Agency outside the submitted work. Dr Hartert reported grants from NIH and the World Health Organization during the conduct of the study and personal fees from Pfizer and Sanofi-Pasteur outside the submitted work. Dr Bacharier reported grants from NIH/National Institute of Allergy and Infectious Diseases (NIAID) during the conduct of the study and personal fees from GlaxoSmithKline, Genentech/Novartis, Merck, DBV Technologies, Teva, Boehringer Ingelheim, AstraZeneca, Webscape/WebMD, Sanofi/Regeneron, Circassia, Vertex, and Elsevier outside the submitted work. Dr Ownby reported grants from NIH during the conduct of the study. Dr Zoratti reported grants from NIAID during the conduct of the study. Dr Wright reported grants from NIH during the conduct of the study. Dr Martinez reported grants from Office of the Director (UH3OD023282) during the conduct of the study and grants from NIH/National Heart, Lung, and Blood Institute (HL132523, HL139054, HL091889, HL130045, HL098112, HL056177, HL137851, HL132523), NIH/NIAID (AI126614, AI148104), and NIH/National Institute of Environmental Health Sciences (NIEHS) (ES006614) outside the submitted work. Dr Seroogy reported grants from NIH during the conduct of the study and outside the submitted work. Dr Johnson reported grants from NIH during the conduct of the study. Dr Jackson reported grants from NIH during the conduct of the study and grants and/or personal fees from GlaxoSmithKline, Sanofi, Regeneron, Novartis, Pfizer, and Vifor Pharma outside the submitted work. Dr Gern reported grants from NIH during the conduct of the study and personal fees from AstraZeneca and Gossamer Bio outside the submitted work. Dr Gold reported grants from NIH during the conduct of the study. No other disclosures were reported.

Funding/Support: This work was supported by NIH grant 5UG3OD023282. The Harvard NIEHS Center Grant P30-ES000002 is a source of support for Drs Zanobetti and Coull.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Group Information: A complete list of the members of the Children's Respiratory and Environmental Workgroup (CREW) Consortium appears in Supplement 2.

Additional Information: The Environmental Influences on Child Health Outcomes (ECHO) program supports multiple longitudinal studies using existing cohorts to investigate how environmental exposures, including physical, chemical, biological, social, behavioral, natural, and built environments, influence child health and development. The studies focus on 5 key pediatric outcomes that have a high public health impact: prenatal, perinatal, and postnatal outcomes; upper and lower airway; obesity; neurodevelopment; and positive health. See https://www.nih.gov/research-training/environmental-influences-child-health-outcomes-echo-program for details. The Children's Respiratory and Environmental Workgroup (CREW) is funded by the ECHO program and consists of 12 individual cohort studies and 3 scientific centers. The goal of CREW program is to develop a better understanding of how early life environmental exposures and host factors interact

to promote the development of specific asthma endotypes.

REFERENCES

1. Stern DA, Morgan WJ, Halonen M, Wright AL, Martinez FD. Wheezing and bronchial hyper-responsiveness in early childhood as predictors of newly diagnosed asthma in early adulthood: a longitudinal birth-cohort study. *Lancet*. 2008;372(9643):1058-1064. doi:10.1016/S0140-6736(08)61447-6

2. Ly NP, Gold DR, Weiss ST, Celedón JC. Recurrent wheeze in early childhood and asthma among children at risk for atopy. *Pediatrics*. 2006;117(6):e1132-e1138. doi:10.1542/peds.2005-2271

3. Keet CA, Matsui EC, McCormack MC, Peng RD. Urban residence, neighborhood poverty, race/ethnicity, and asthma morbidity among children on Medicaid. *J Allergy Clin Immunol*. 2017;140(3):822-827. doi:10.1016/j.jaci.2017.01.036

4. Beck AF, Moncrief T, Huang B, et al. Inequalities in neighborhood child asthma admission rates and underlying community characteristics in one US county. *J Pediatr*. 2013;163(2):574-580. doi:10.1016/j.jpeds.2013.01.064

5. Sullivan PW, Ghushchyan V, Kavati A, Navaratnam P, Friedman HS, Ortiz B. Health disparities among children with asthma in the United States by place of residence. *J Allergy Clin Immunol Pract*. 2019;7(1):148-155. doi:10.1016/j.jaip.2018.05.001

6. Johnson CC, Chandran A, Havstad S, et al; Environmental Influences on Child Health Outcomes (ECHO) collaborators. US childhood asthma incidence rate patterns from the ECHO Consortium to identify high-risk groups for primary prevention. *JAMA Pediatr*. 2021;175(9):919-927. doi:10.1001/jamapediatrics.2021.0667

7. Johnson CC, Havstad SL, Ownby DR, et al; Children's Respiratory and Environmental Workgroup in the ECHO Consortium. Pediatric asthma incidence rates in the United States from 1980 to 2017. *J Allergy Clin Immunol*. 2021;148(5):1270-1280. doi:10.1016/j.jaci.2021.04.027

8. Gern JE, Jackson DJ, Lemanske RF Jr, et al. The Children's Respiratory and Environmental Workgroup (CREW) birth cohort consortium: design, methods, and study population. *Respir Res*. 2019;20(1):115. doi:10.1186/s12931-019-1088-9

9. Ryan PH, Brokamp C, Blossom J, et al. A distributed geospatial approach to describe community characteristics for multisite studies. *J Clin Transl Sci*. 2021;5(1):e86. doi:10.1017/cts.2021.7

10. Bland JM, Altman DG. Survival probabilities (the Kaplan-Meier method). *BMJ*. 1998;317(7172):1572. doi:10.1136/bmj.317.7172.1572

11. Cox DR. Regression models and life-tables. *J R Stat Soc B*. 1972;34(2). doi:10.1111/j.2517-6161.1972.tb00899.x

12. Lin DY, Ying Z. Semiparametric analysis of the additive risk model. *Biometrika*. 1994;81(1). doi:10.1093/biomet/81.1.61

13. Aalen OO. A linear regression model for the analysis of life times. *Stat Med*. 1989;8(8):907-925. doi:10.1002/sim.4780080803

14. Schaubel DE, Wei G. Fitting semiparametric additive hazards models using standard statistical software. *Biom J*. 2007;49(5):719-730. doi:10.1002/bimj.200610349

15. Asthma and Allergy Foundation of America. Asthma disparities: reducing burden on racial and ethnic minorities. Accessed May 28, 2021. https://www.aafa.org/asthma-disparities-burden-on-minorities.aspx

16. Moorman JE, Rudd RA, Johnson CA, et al. National surveillance for asthma: United States, 1980-2004. *MMWR Surveill Summ*. 2007;56(8):1-54. https://www.cdc.gov/mmwr/preview/mmwrhtml/ss5608a1.htm

17. Gold DR, Wright R. Population disparities in asthma. *Annu Rev Public Health*. 2005;26:89-113. doi:10.1146/annurev.publhealth.26.021304.144528

18. Coogan PF, Castro-Webb N, Yu J, O'Connor GT, Palmer JR, Rosenberg L. Neighborhood and individual socioeconomic status and asthma incidence in African American women. *Ethn Dis*. 2016;26(1):113-122. doi:10.18865/ed.26.1.113

19. Cardet JC, Louisias M, King TS, et al; Vitamin D Add-On Therapy Enhances Corticosteroid Disparities Working Group members on behalf of the AsthmaNet investigators. Income is an independent risk factor for worse asthma outcomes. *J Allergy Clin Immunol*. 2018;141(2):754-760.e3. doi:10.1016/j.jaci.2017.04.036

20. Auger KA, Kahn RS, Simmons JM, et al. Using address information to identify hardships reported by families of children hospitalized with asthma. *Acad Pediatr*. 2017;17(1):79-87. doi:10.1016/j.acap.2016.07.003

21. Schraufnagel DE, Blasi F, Kraft M, Gaga M, Finn PW, Rabe KF; ATS/ERS Committee on Disparities in Respiratory Health. An official American Thoracic Society/European Respiratory Society policy statement: disparities in respiratory health. *Am J Respir Crit Care Med*. 2013;188(7):865-871. doi:10.1164/rccm.201308-1509ST

22. Harrell SP. A multidimensional conceptualization of racism-related stress: implications for the well-being of people of color. *Am J Orthopsychiatry*. 2000;70(1):42-57. doi:10.1037/h0087722

23. Dailey AB, Kasl SV, Holford TR, Lewis TT, Jones BA. Neighborhood- and individual-level socioeconomic variation in perceptions of racial discrimination. *Ethn Health*. 2010;15(2):145-163. doi:10.1080/13557851003592561