ORIGINAL ARTICLE

Racial Segregation and Respiratory Outcomes among Urban Black Residents with and at Risk of Chronic Obstructive Pulmonary Disease

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Abstract

Rationale: Racial residential segregation has been associated with worse health outcomes, but the link with chronic obstructive pulmonary disease (COPD) morbidity has not been established.

Objectives: To investigate whether racial residential segregation is associated with COPD morbidity among urban Black adults with or at risk of COPD.

Methods: Racial residential segregation was assessed using isolation index, based on 2010 decennial census and baseline address, for Black former and current smokers in the multicenter SPIROMICS (Subpopulations and Intermediate Outcome Measures in COPD Study), a study of adults with or at risk for COPD. We tested the association between isolation index and respiratory symptoms, physiologic outcomes, imaging parameters, and exacerbation risk among urban Black residents, adjusting for established COPD risk factors, including smoking. Additional mediation analyses were conducted for factors that could lie on the pathway between segregation and COPD outcomes, including individual and neighborhood socioeconomic status, comorbidity burden, depression/anxiety, and ambient pollution.

Measurements and Main Results: Among 515 Black participants, those residing in segregated neighborhoods (i.e., isolation index $\geq$0.6) had worse COPD Assessment Test score ($\beta = 2.4$; 95% confidence interval [CI], 0.7 to 4.0), dyspnea (modified Medical Research Council scale; $\beta = 0.29$; 95% CI, 0.10 to 0.47), quality of life (St. George's Respiratory Questionnaire; $\beta = 6.1$; 95% CI, 2.3 to 9.9), and cough and sputum ($\beta = 0.8$; 95% CI, 0.1 to 1.5); lower FEV_1% predicted ($\beta = -7.3$; 95% CI, -10.9 to -3.6); higher rate of any and severe exacerbations; and higher percentage emphysema ($\beta = 2.3$; 95% CI, 0.7 to 3.9) and air trapping ($\beta = 3.8$; 95% CI, 0.6 to 7.1). Adverse associations attenuated with adjustment for potential mediators but remained robust for several outcomes, including dyspnea, FEV_1% predicted, percentage emphysema, and air trapping.

Conclusions: Racial residential segregation was adversely associated with COPD morbidity among urban Black participants and supports the hypothesis that racial segregation plays a role in explaining health inequities affecting Black communities.

Keywords: COPD; health disparities; racial segregation; residential segregation; neighborhood

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At a Glance Commentary

Scientific Knowledge on the Subject: Racial residential segregation has been associated with worse chronic disease outcomes in the United States, but the association of respiratory health and chronic obstructive pulmonary disease (COPD) is unknown.

What This Study Adds to the Field: Racial residential segregation is adversely associated with COPD morbidity among urban Black individuals. Some of the adverse associations are explained by other risk factors that are known to be linked with racial residential segregation, such as socioeconomic status, psychosocial stressors, comorbidities, and environmental exposure, but not all. There remains an unexplained association between racial residential segregation and COPD outcomes for urban Black individuals.

Chronic obstructive pulmonary disease (COPD) is a progressive lung disease and is the third leading cause of death from chronic disease in the United States (1). Historically, the prevalence of COPD has been higher for white than for Black individuals, but recent studies suggest that Black individuals may suffer worse COPD morbidity, across a variety of measures (2–9). Several factors likely contribute to racial disparities, including biological factors (10), individual and neighborhood socioeconomic differences (11), and structural racism (12). In particular, racial residential segregation, defined as "the degree to which two or more [racial] groups live separately from one another, in different parts of the urban environment" (13), is a known risk factor for numerous health outcomes for Black individuals (14, 15). Racial residential segregation may lead to worse health status in chronic conditions via mechanisms including differential healthcare access (16, 17), environmental exposures (18), economic opportunities (11), political disenfranchisement (19), social isolation (20), and race-based discrimination and perceived stress (21). Although some studies have linked racial residential segregation to other respiratory-related outcomes (e.g., lung cancer and asthma) (22–25), to our knowledge, no studies have assessed the link between racial residential segregation and COPD morbidities, despite evidence suggesting worse COPD outcomes among Black compared with white individuals with COPD (2–9).

We hypothesize that racial residential segregation is a significant predictor of COPD morbidity for Black individuals in the United States. SPIROMICS (Subpopulations and Intermediate Outcome Measures in COPD Study) is a multicenter U.S. cohort study focused on COPD health, with 19% recruitment of Black participants (26), and provides a valuable mix of detailed individual characterization in combination with neighborhood-level data. Geocoded data provides access to block group and tract-level census information in a subset of this study (SPIROMICS AIR [SPIROMICS Air Pollution Study]) (27), allowing insights into the association between racial segregation and COPD health.

Methods

Study Design

SPIROMICS AIR is an ancillary study of SPIROMICS (27), providing address-based geographic identification links for 2,924 participants across the United States, aged 40–80 years, current or former smokers (pack-years $\geq$ 20), either with or without evidence of airflow obstruction. The current cross-sectional analysis was performed on baseline data collected between 2010 and 2015, with up to 3 years of follow-up exacerbation data, among those who self-reported as Black race, regardless of ethnicity (5.6% Hispanic). Healthy control subjects with $\leq$1 pack-year smoking and participants who were missing a geographic identifier for the 2010 Census were excluded from the analysis. Participants residing in rural areas, based on census definition (28), were excluded because of low sample size ($n = 3$) and also because racial residential segregation has typically been operationalized within urban setting (13, 29), resulting in 515 Black individuals in the study sample (*see* Figure E1 in the online supplement).

Racial Residential Segregation

Racial residential segregation was measured with the isolation index, an established descriptor of segregation (13), which has been used in prior health studies (30–32) (*see* the online supplement for details). The isolation index for Black ("Black isolation index") was

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This article has a related editorial.

This article has an online supplement, which is accessible from this issue's table of contents online at www.atsjournals.org.

Figure 1. Potential pathways between racial residential segregation and COPD health disparities. COPD = chronic obstructive pulmonary disease; SES = socioeconomic status.

calculated based on the 2010 decennial census (33) and measures the degree to which a Black resident is likely to be in contact with other Black residents (as opposed to members of other racial/ethnic groups) within his/her neighborhood or census tract (13). The index can range from 0 to 1, with "1" representing complete isolation or segregation of Black residents from other racial/ethnic groups within their neighborhoods.

Outcomes

Questionnaires included the COPD Assessment Test (CAT) (34), modified Medical Research Council (mMRC) scale (35), St. George's Respiratory Questionnaire (SGRQ) (36), and ease of cough and sputum questionnaire (37). Physiologic data included FEV_1% predicted (38) and 6MWD (6-minute-walk distance), performed and interpreted per American Thoracic Society standards (39). Radiographic outcomes included percentage emphysema (voxels < -950 HU on full inspiratory scan) (40) and gas trapping (voxels < -856 HU on full expiratory scan) (41) via quantitative computed tomography (CT) scan.

Participants were followed up to 3 years in the SPIROMICS I phase, with quarterly phone calls for exacerbation frequency, based on self-report of antibiotics/steroid use, unscheduled physician visits, and emergency department visit/hospitalization for COPD. Severe exacerbations were defined as events requiring emergency department visit or hospitalization.

Statistical Analysis

The Black isolation index at the participant's census tract was modeled both dichotomously, as ≥ 0.6 versus < 0.6 (29, 30), and continuously per SD increase (0.32) to examine the association between racial residential segregation and COPD measures. Linear and negative binomial regressions of continuous and count respiratory outcomes were run respectively on the isolation index, adjusting for potential confounders: COPD status, age, sex, smoking status, pack-years, marital status, obesity, occupational exposure, and total population size of a tract. Mediation analysis was performed to estimate the direct and indirect (or mediated) association between racial segregation and COPD health according to a prespecified directed acyclic graph (Figure 1). The potential mediators consisted of participants' individual and neighborhood socioeconomic status (SES; annual household income, educational attainment, and a composite score of neighborhood socioeconomic markers; *see* the online supplement for additional detail), comorbidity burden (42), and depression or anxiety (43). Analyses were additionally adjusted for ambient pollution as a potential mediator, but because $<20\%$ of the samples were missing pollutant information, multiple imputation analysis was incorporated and the analysis done separately (*see* the online supplement). The variables for air pollution consisted of ambient 1-year average ozone and particulate matter ≤ 2.5 μm in aerodynamic diameter ($PM_{2.5}$) concentrations, model-predicted pollutant concentrations outside the participant's home over the course of 1 year (27). The recommended nonparametric bootstrap approach (44) was used to obtain the statistical inferences of the mediated effects and mediation proportion based on the 95% confidence interval (95% CI).

As an additional sensitivity analysis, effect modification by COPD status on differences in outcomes by racial residential segregation was tested by running a multiplicative interaction model with an interaction term between COPD status and isolation index included in the adjusted model. An additional stratified model was run among participants with COPD only. Also, to explore the link between racial segregation and COPD morbidity for white individuals, the regression of COPD outcomes on isolation index (Black isolation) was run among white participants only (*see* the online supplement).

All analyses were performed using Stata, version 15.1 (Stata Corp). Statistical significance was defined as $P < 0.05$.

Table 1. Characteristics of Study Participants (Black Participants with or at Risk of COPD)

	All (*N* = *515*)	Isolation < 0.6: Nonsegregated (*N* = *279*)	Isolation ⩾ 0.6: Segregated (*N* = *236*)	*P* Value
Demographic				
Age, yr	58.2 ± 9.0	58.8 ± 8.9	57.5 ± 9.0	0.114
Sex, F	259 (50.3)	120 (43.0)	139 (58.9)	**<0.001**
More than high school education	228 (44.4)	131 (47.1)	97 (41.1)	0.171
Household Income				0.186
<$15,000	203 (39.4)	106 (38.0)	97 (41.1)	
$15,000–$34,999	101 (19.6)	55 (19.7)	46 (19.5)	
$35,000–$49,999	42 (8.2)	22 (7.9)	20 (8.5)	
$50,000–$74,999	35 (6.8)	23 (8.2)	12 (5.1)	
>$75,000	16 (3.1)	13 (4.7)	3 (1.3)	
Missing/declined to answer	118 (22.9)	60 (21.5)	58 (24.6)	
Married	117 (22.8)	70 (25.2)	47 (20.0)	0.164
Occupational exposure*	270 (53.4)	143 (52.4)	127 (54.5)	0.633
Obese	204 (39.6)	117 (41.9)	87 (36.9)	0.241
Comorbidity count†	2.4 ± 1.5	1.9 ± 1.5	2.4 ± 1.5	**<0.001**
Depression or anxiety‡	188 (37.4)	91 (33.6)	97 (41.8)	0.057
Currently smoking	325 (63.7)	169 (61.5)	156 (66.4)	0.249
Pack-years	40.8 ± 17.2	40.1 ± 16.4	41.7 ± 18.1	0.313
COPD	273 (53.0)	137 (49.1)	136 (57.6)	0.053
Ambient pollution				
Ozone, 1-yr average concentration	22.0 ± 4.6	21.4 ± 4.7	23.0 ± 4.2	**0.001**
$PM_{2.5}$, 1-yr average concentration	10.4 ± 1.5	10.3 ± 1.8	10.4 ± 1.1	0.411
Respiratory morbidity				
FEV_1% predicted	76.9 ± 27.5	81.3 ± 26.9	71.7 ± 27.4	**<0.001**
CAT	16.1 ± 8.9	14.6 ± 8.7	17.8 ± 8.8	**<0.001**
mMRC	1.2 ± 1.1	1.0 ± 1.0	1.4 ± 1.1	**<0.001**
SGRQ	37.6 ± 21.7	33.4 ± 21.4	42.6 ± 21.1	**<0.001**
Cough and sputum	9.9 ± 3.8	9.4 ± 3.7	10.4 ± 3.9	**0.003**
6MWD	412.1 ± 132.3	409.3 ± 106.6	415.4 ± 157.7	0.614
CT scan findings				
% Emphysema	7.2 ± 10.6	6.1 ± 9.6	8.4 ± 11.6	**0.013**
% Air trapping	22.1 ± 22.8	19.7 ± 21.1	24.9 ± 24.5	**0.011**
Exacerbations				
Any (number per year, prospective)§	0.50 ± 1.06	0.34 ± 0.75	0.69 ± 1.32	**<0.001**
Severe (number per year, prospective)‖	0.26 ± 0.77	0.14 ± 0.32	0.40 ± 1.07	**<0.001**

Definition of abbreviations: 6MWD = 6-minute-walk distance; CAT = COPD Assessment Test; COPD = chronic obstructive pulmonary disease; CT = computed tomography; mMRC = modified Medical Research Council; $PM_{2.5}$ = particulate matter ⩽2.5 μm in aerodynamic diameter; SGRQ = St. George's Respiratory Questionnaire.

Data are shown as *n* (%) or mean ± SD.

Bold values are statistically significant.

*Occupational exposure to hazardous vapor, gas, dust, or fumes in the longest job held.

†Comorbidity count based on yes/no answer to the following symptoms: asthma, cardiovascular heart disease, diabetes, cardiovascular heart failure, stroke, hypertension, gastroesophageal reflux disease, anemia, and sleep apnea.

‡Depression or anxiety symptom (dichotomous) based on the Hospitalization Anxiety Depression Scale with the cutoff of ⩾8 for either the Depression subscale or the Anxiety subscale.

§"Any" exacerbation defined as the total number of oral antibiotics or steroid use due to adverse respiratory symptoms during the entire duration of the study. The rate of any exacerbation represented the yearly average (365 × total number of any exacerbations/total days in the study).

‖"Severe" exacerbation defined as the total number of hospitalizations or emergency room visits due to respiratory symptoms during the duration of the study. The rate of severe exacerbation represented the yearly average (365 × total number of severe exacerbations/total days in the study).

Results

The study population included 515 Black participants residing in 465 census block groups across 422 census tracts in 45 counties and 14 states (Figure E2). The median isolation index was 0.51 (interquartile range [IQR], 0.23–0.89) (at tract-level), ranging from 0.005 (least segregated) to 0.99 (most segregated). Nearly half of Black participants (*n* = 236, 46%) resided in tracts with an isolation score above 0.6—henceforth referred to as "segregated" neighborhoods. These neighborhoods had a smaller total

Table 2. Adjusted Associations between Isolation Index and COPD Outcomes among Black Participants with or at Risk of COPD ($N = 515$)

	Segregation as Continuous Variable		Segregated vs. Nonsegregated Neighborhoods	
	Estimated Difference (95% CI) for a One-SD Increase*	*P* Value	Estimated Difference (95% CI) between Isolation ⩾0.6 and <0.6†	*P* Value
Respiratory morbidity				
CAT	1.38 (0.58 to 2.19)	**0.001**	2.37 (0.76 to 3.97)	**0.004**
mMRC	0.16 (0.07 to 0.25)	**0.001**	0.29 (0.10 to 0.47)	**0.003**
SGRQ	3.39 (1.49 to 5.28)	**<0.001**	6.09 (2.32 to 9.87)	**0.002**
Cough and sputum	0.36 (0.01 to 0.71)	**0.041**	0.82 (0.11 to 1.53)	**0.024**
FEV_1% predicted	−4.37 (−6.21 to −2.53)	**<0.001**	−7.28 (−10.93 to −3.63)	**<0.001**
6MWD, meters	5.94 (−5.87 to 17.75)	0.324	11.05 (−12.52 to 34.62)	0.357
Exacerbations‡				
Any, IRR	1.36 (1.14 to 1.63)	**0.001**	1.70 (1.19 to 2.43)	**0.003**
Severe, IRR	1.51 (1.21 to 1.89)	**<0.001**	2.04 (1.35 to 3.09)	**0.001**
CT scan findings				
% Emphysema	1.41 (0.69 to 2.13)	**<0.001**	2.35 (0.84 to 3.85)	**0.002**
% Air trapping	2.11 (0.54 to 3.67)	**0.008**	4.53 (1.43 to 7.63)	**0.004**

Definition of abbreviations: 6MWD = 6-minute-walk distance; CAT = COPD Assessment Test; CI = confidence interval; COPD = chronic obstructive pulmonary disease; CT = computed tomography; IRR = incidence rate ratio; mMRC = modified Medical Research Council; SGRQ = St. George's Respiratory Questionnaire.

All models were adjusted for COPD status, age, sex, smoking status, pack-years, obesity, marital status, occupational exposure, and total population size. In the exacerbation models, participant total follow-up days in the study was specified as offset.

Bold values are statistically significant.

*Predicted change in the level of respiratory morbidity/CT scan finding or the IRR of exacerbations for a one-SD (0.32) increase in the continuous isolation index score, adjusting for covariates.

†Estimated mean difference in the level of respiratory morbidity/CT scan finding or the IRR of exacerbation between those residing in the segregated neighborhoods (isolation index ⩾0.6) and in the nonsegregated neighborhoods (isolation index <0.6), adjusting for covariates.

‡"Any" exacerbation defined as the total number of oral antibiotics or steroid use due to adverse respiratory symptoms during the duration of the study. "Severe" exacerbation defined as the total number of hospitalizations or emergency room visits due to adverse respiratory symptoms during the duration of the study. The effect estimates for exacerbation outcomes represent the IRR.

population size (3,824 vs. 4,838; $P < 0.001$), higher poverty rate (25.0% vs. 17.9%; $P < 0.001$), lower median household income ($33,000 vs. $45,300; $P < 0.001$), and higher unemployment rate (9.0% vs. 6.6%; $P < 0.001$). There was no segregation difference in neighborhoods' proportion of adults with less than a high school degree.

Participants had a mean age of 58.2 years, half (50%) were women, and the majority (64%) were current smokers (mean 41 pack-year smoking history). Approximately half (53%) had spirometry-confirmed airways obstruction (COPD) (Table 1). Less than a quarter (23%) were married, and less than half (44%) had education beyond high school. The mean (SD) follow-up days for prospective exacerbations was 768 (371) days. Black participants residing in segregated neighborhoods were more likely to be female, had a greater comorbidity burden, and had home addresses associated with higher concentration of ambient ozone than counterparts in nonsegregated tracts. There were no significant differences in age, educational attainment, income, marital status, occupational hazard, obesity, smoking status, pack-years, COPD status, and ambient $PM_{2.5}$ level by residential segregation.

For respiratory outcomes, Black participants in segregated neighborhoods had worse lung function, worse clinical disease severity (CAT, mMRC, SGRQ, and cough and sputum), worse CT scan findings (emphysema and air trapping), and a higher rate of prospective exacerbations as compared with counterparts in nonsegregated neighborhoods. 6MWD showed no significant differences by residential segregation (Table 1).

Multivariable Regression

After adjusting for confounders, a one-SD increase in residential segregation (isolation index) was associated with more respiratory symptoms as measured by CAT ($\beta = 1.38$; 95% CI, 0.58 to 2.19), dyspnea score (mMRC; $\beta = 0.16$; 95% CI, 0.07 to 0.25), cough and sputum production ($\beta = 0.82$; 95% CI, 0.11 to 1.53), worse respiratory quality of life (SGRQ; $\beta = 3.4$; 95% CI, 1.5 to 5.3), and lower FEV_1% predicted ($\beta = -4.4$; 95% CI, −6.2 to −2.5) (Table 2 and Figure 1). A one-SD increase in residential segregation was associated with a 36% higher rate of any exacerbation (odds ratio [OR], 1.36; 95% CI, 1.14 to 1.63) as well as a 51% higher rate of severe exacerbations requiring acute healthcare utilization (OR, 1.51; 95% CI, 1.21 to 1.89) over study follow-up. Furthermore, a one-SD increase in the isolation index was associated with worse CT measures, including higher percentage emphysema ($\beta = 1.4$; 95% CI, 0.7 to 2.1) and air trapping ($\beta = 2.1$; 95% CI, 0.5 to 3.7). There were no significant associations between residential segregation and 6MWD. The linearity assumption was satisfied for all outcomes; no statistically significant improvement in model fit was found with nonlinear polynomial model specifications for isolation index.

When using a dichotomized isolation index (⩾0.6 vs. <0.6), results were similar (Table 2 and Figure 2). Black participants residing in segregated tracts (vs. nonsegregated) had worse CAT and SGRQ scores, with effect sizes larger than the minimum clinically important difference for both measures (45, 46). Furthermore, those residing in segregated tracts

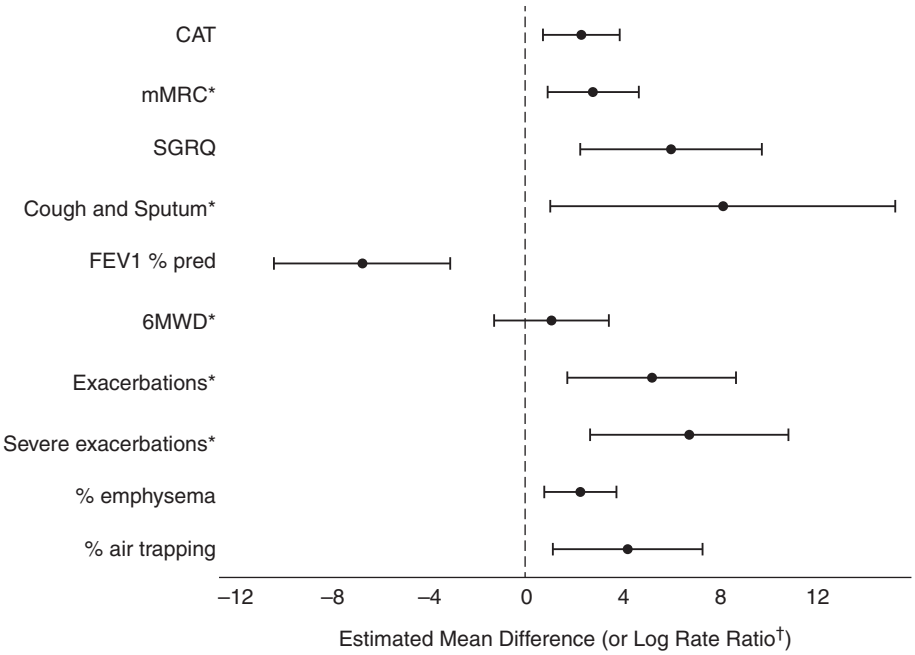

Figure 2. Black participants with or at risk of chronic obstructive pulmonary disease living in segregated neighborhoods have worse chronic obstructive pulmonary disease outcomes than their counterparts living in nonsegregated neighborhoods. Above demonstrates the estimated mean difference (or the log incidence rate) and 95% confidence intervals of respiratory morbidity/computed tomography scan findings (or exacerbations) for Black participants residing in tracts with isolation ⩾0.6 (vs. isolation <0.6), adjusting for age, sex, smoking status, pack-years, obesity, marital status, occupational exposure, and total population size. In exacerbation models, participant total follow-up days in the study was specified as offset. *Estimated mean differences were rescaled to fit the chart: multiplied by 10 for mMRC, Cough and Sputum, any exacerbation (log rate), and severe exacerbation (log rate); multiplied by 1/10 for 6MWD. †For any exacerbation and severe exacerbation, the point estimate and 95% confidence interval represents the log rate ratio (multiplied by 10 to fit the chart's scale). 6MWD = 6-minute-walk distance; CAT = COPD Assessment Test; COPD = chronic obstructive pulmonary disease; mMRC = modified Medical Research Council; SGRQ = St. George's Respiratory Questionnaire.

had worse dyspnea, worse cough and sputum, and lower FEV_1% predicted as well as worse percentage emphysema and air trapping. Those residing in segregated tracts had almost double the risk of any or severe exacerbations. Similarly, no significant segregation differences were found for 6MWD.

Mediation Analysis

When additionally controlling for potential mediators—individual and neighborhood SES, comorbidity count, and depression or anxiety—the associations between segregation and COPD outcomes attenuated but generally remained significant (Table 3). The largest mediation was shown in cough and sputum score, representing 49.3% mediation of the segregation difference in the score between those residing in segregated (vs. nonsegregated) neighborhoods (Table 3). For all outcomes except CAT and cough and sputum, the effect estimates of segregation remained robust to the adjustment by the mediators (Table 3). When additionally adjusting for ambient pollution (1-year average ozone and $PM_{2.5}$), there was further attenuation in the segregation effect estimates, where racial segregation was no longer statistically significantly associated with SGRQ and both exacerbation measures (Table E1). Ambient pollution and other mediators explained 54.6% of the segregation differences in SGRQ ($\beta_{mediated} = 3.3$; 95% CI, 0.7–5.8) and 34.5% and 39.7% of any and severe exacerbation risk, respectively, although the effect estimates of mediation were themselves not statistically significant (Table E1). For dyspnea, lung function, percentage emphysema, and percentage gas trapping, the segregation differences persisted even with the additional adjustment by all measured mediators including ambient pollution (Table E1).

Effect Modification by COPD Status

The segregation difference in FEV_1% predicted was greater among those with COPD ($\beta_{interaction} = -7.5$; 95% CI, −14.5 to −0.7) compared with those without, whereas the segregation difference in the odds of any exacerbation was greater among those without (compared with those with) COPD ($OR_{interaction} = 0.32$; $P = 0.003$). For other outcomes, segregation differences were generally larger among individuals with COPD compared with those without, although the differences by COPD status were not statistically significant. The results among only those with COPD were largely consistent with those among the combined population including at-risk individuals (Table E2).

Racial Segregation and COPD Morbidity among White Participants

There were 1,783 white participants, among whom the median Black isolation index was 0.04 (IQR, 0.02–0.11), with 2% living in Black racially segregated neighborhoods. White residents living in Black racially segregated neighborhoods similarly had worse COPD morbidity for several outcomes, but the association of segregation and dyspnea, odds of any exacerbations, and percentage emphysema were smaller in magnitude and not statistically significant for white participants in comparison with Black participants (Table E3). The Black–white difference in segregation effect estimates were not statistically significant for any outcomes ($P_{interaction} > 0.05$ for all).

Table 3. Mediation Analysis: Adjusted Associations between Dichotomous Isolation Index and COPD Outcomes among Black Participants, Additionally Adjusted for Potential Mediators

	Total* Associations: Estimated Difference (95% CI) between Isolation ⩾0.6 and <0.6†	Direct‡ Associations: Estimated Difference (95% CI) between Isolation ⩾0.6 and <0.6†	Mediated (Indirect)§ Associations: Estimated Difference (95% CI) between Isolation ⩾0.6 and <0.6†	Mediation Percentage: Mediated Association/ Total Association‖
Respiratory morbidity				
CAT	**2.37 (0.76 to 3.97)**	1.43 (−0.10 to 2.96)	**0.94 (0.10 to 1.77)**	**39.7**%
mMRC	**0.29 (0.10 to 0.47)**	**0.21 (0.03 to 0.39)**	0.07 (−0.02 to 0.16)	25.4%
SGRQ	**6.09 (2.32 to 9.87)**	**3.68 (0.30 to 7.06)**	**2.41 (0.09 to 4.85)**	**39.6**%
Cough and sputum	**0.82 (0.11 to 1.53)**	0.42 (−0.29 to 1.12)	**0.40 (0.11 to 0.73)**	**49.3**%
FEV_1% predicted	**−7.28 (−10.93 to −3.63)**	**−5.86 (−9.60 to −2.11)**	**−1.42 (−3.02 to −0.06)**	**19.5**%
6MWD, meters	11.05 (−12.52 to 34.62)	17.82 (−5.34 to 40.98)	−6.77 (−15.33 to 1.46)	−61.2%
Exacerbations¶				
Any, IRR	**1.70 (1.19 to 2.43)**	**1.60 (1.10 to 2.34)**	1.06 (0.91 to 1.31)	11.6%
Severe, IRR	**2.04 (1.35 to 3.09)**	**1.84 (1.16 to 2.93)**	1.11 (0.92 to 1.42)	14.4%
CT scan findings				
% Emphysema	**2.35 (0.84 to 3.85)**	**2.48 (0.84 to 4.12)**	−0.13 (−0.65 to 0.40)	−5.7%
% Air trapping	**4.53 (1.43 to 7.63)**	**4.54 (1.30 to 7.77)**	−0.01 (−1.12 to 1.16)	−0.2%

Definition of abbreviations: 6MWD = 6-minute-walk distance; CAT = COPD Assessment Test; CI = confidence interval; COPD = chronic obstructive pulmonary disease; CT = computed tomography; IRR = incidence rate ratio; mMRC = modified Medical Research Council; SES = socioeconomic status; SGRQ = St. George's Respiratory Questionnaire.

Bold values are statistically significant.

*For total associations, all models were adjusted for COPD status, age, sex, smoking status, pack-years, obesity, marital status, occupational exposure, and total population size. In the exacerbation models, participants' total follow-up days in the study was specified as offset.

†Estimated mean difference in the level of respiratory morbidity/CT scan finding or the IRR of exacerbation between those residing in the segregated neighborhoods (isolation index ⩾0.6) and in the nonsegregated neighborhoods (isolation index <0.6), adjusting for covariates.

‡For direct association, all models were additionally adjusted for individual SES (education and income) and neighborhood SES (a composite score of neighborhood poverty rate, median household income, unemployment rate, and educational attainment), comorbidity count, and depression or anxiety. Comorbidity count was based on a yes/no answer to the following symptoms: asthma, cardiovascular heart disease, diabetes, cardiovascular heart failure, stroke, hypertension, gastroesophageal reflux disease, anemia, and sleep apnea. Depression or anxiety (dichotomous) was based on the Hospitalization Anxiety Depression Scale with the cutoff of ⩾8 for either the Depression subscale or the Anxiety subscale.

§Mediated (or indirect) association is the difference between the total and direct associations and represents the mean difference in the level of respiratory morbidity/CT scan finding or the IRR of exacerbation between those residing in the segregated neighborhoods (isolation index ⩾0.6) and in the nonsegregated neighborhoods (isolation index <0.6) that is attributable to the mean differences in the mediating factors (SES, comorbidity, depression/anxiety) across the dichotomous isolation.

‖Mediation percentage is the ratio of mediated association to total association (or, equivalently, 1 − direct association/total association) in percentage terms and represents the proportional reduction in racial segregation's association with COPD outcome from before and after the adjustment with the mediators.

¶"Any" exacerbation defined as the total number of oral antibiotics or steroid use due to worsening respiratory symptoms during the duration of the study. "Severe" exacerbation defined as the total number of hospitalizations or emergency room visits due to adverse respiratory symptoms during the duration of the study. Effect estimates for exacerbation outcomes represent the IRR.

Discussion

Although racial disparities in COPD outcomes have been reported previously (6, 8, 47), this is the first study that links racial residential segregation to worse COPD outcomes among Black adults in the United States. Racial residential segregation was associated with worse outcomes across a range of outcomes (subjective symptom, quality-of-life scores, spirometry, imaging findings, and COPD exacerbation rate) among Black participants with at least a 20 pack-year smoking history residing in urban areas in the United States. As in prior work demonstrating the impact of segregation on racial health disparities (12, 14), the adverse effect of residing in a segregated area was persistent even when adjusting for potentially confounding risk factors, including participants' smoking status/pack-year history and occupational exposures. In addition, associations of racial segregation were partially mediated by factors such as SES, comorbidity burden, depression/anxiety, and ambient pollution; however, there continue to be unmeasured mechanisms by which racial residential segregation may associate with more severe respiratory outcomes.

The detrimental health effect of residential segregation has been documented in other health outcomes (14, 48) and, specifically, has been suggested to be associated with poor outcomes in other respiratory ailments, such as lung cancer (22, 23) and asthma risk (24, 49). For example, lung cancer mortality rates among Black adults in the United States are more than 10% higher in the most segregated areas (22). In our study, the SPIROMICS cohort of Black participants resided in tracts with a substantially higher isolation index (median, 0.51; IQR, 0.23–0.89) than the national median (0.05; IQR, 0.01–0.17)—based on 2010 decennial census data (33)—and higher levels of racial residential segregation associated with worse COPD outcomes consistently across morbidity measures: higher participant-reported respiratory symptoms and exacerbations, worse quality of life, lower lung function (FEV_1% predicted), and higher severity of COPD-related CT measures.

Furthermore, the differences in COPD metrics between those residing in high- versus low-segregation areas exceeded standards for clinical significance, specifically for symptoms and quality of life (45, 46), and reflected a greater than doubling in the risk of acute healthcare visit for severe COPD exacerbation. These results highlight the potential for the substantial adverse clinical impact of neighborhood racial segregation on respiratory outcomes related to COPD. Importantly, the results suggest that living in a predominantly Black racially segregated neighborhood has adverse associations even for white residents, although the literature is mixed regarding the impact of residential segregation on the white population (14, 50).

There are likely a number of contributing mechanisms by which racial residential segregation may associate with more severe respiratory outcomes in this population. Several of these potential factors such as lower SES, high environmental risk exposures (e.g., air pollution) (18, 51), and higher comorbidity and psychological burden may be along the causal pathway to worsened COPD morbidity. Notably, segregated neighborhoods had lower SES; however, the association of racial segregation with COPD outcomes persisted despite adjustment for both individual and a composite neighborhood SES score. Furthermore, participants in segregated neighborhoods had higher comorbidity burden compared with those residing in less segregated neighborhoods; however, differences in outcomes by racial residential segregation generally remained after adjustment for comorbidities and specifically for psychosocial burden as measured by depression and anxiety, suggesting that the presence of chronic disease burden is not sufficient to explain the effect of racial residential segregation on respiratory outcomes. Lastly, ozone and $PM_{2.5}$ exposures are known to be linked with worse COPD outcomes (52), and we found that although $PM_{2.5}$ concentrations were similar, ozone exposures were higher for participants in racially segregated areas compared with those in nonsegregated areas, with suggestion of nonlinearity between isolation index and ozone levels (Figure E3). However, worse respiratory outcomes (i.e., dyspnea, lung function, and emphysema and gas trapping risk) persisted in segregated neighborhoods despite adjustment for pollutants (ozone and $PM_{2.5}$) in addition to SES factors and comorbidity burden.

Our research cannot determine all the pathways between racial residential segregation and COPD morbidity, as there are many unmeasured factors that are correlated with housing patterns in segregated communities, which may include access to medical care (16, 17), healthy food access (53), access to opportunities for a healthy lifestyle (11, 12), community health norms (11), and toxic stress and trauma (21). It is likely that the most segregated neighborhoods bear the greatest historical weight of systemic racism (29), and our results suggest that additional attention is needed to fully understand the impact of racial segregation on respiratory disease.

Our study has several limitations to consider. This study was focused on COPD disparities impacting Black residents across Black residential segregation. Further work is needed to characterize other minority residential segregations and their impact on the respective minority groups. Furthermore, the reference group for the isolation index is non-Black residents, and the impacts and mechanism of racial segregation estimates could vary depending on the racial/ethnic composition of the non-Black population in the census tract. There are several measures of residential segregation that may capture distinct dimensions of segregation and that may differentially impact disease outcomes (13). However, we used a validated metric (isolation index) widely used and particularly recommended in the health literature because the index is considered to best capture the potential pathway by which segregation can impact health via concentration of negative characteristics that correlate with geographic isolation for Black populations (20, 54). In addition, our data are limited to urban areas owing to the low number of Black participants residing in rural areas; however, it is possible that differences in the effects of racial segregation in rural or by geographic regions exist. Similarly, the sample size of the study limited our ability to assess regional differences. Future studies are needed to characterize segregation and its impact on rural communities, to assess potential regional differences, and to fully understand the multiple dimensions of segregation and mechanisms by which racial residential segregation may impact respiratory health.

This is the first study to demonstrate and quantify an adverse association between racial residential segregation and increased COPD morbidity and severity in the U.S. Black population. This study includes outcomes encompassing multiple domains of respiratory morbidity including quality of life, respiratory symptoms, functional status, and objective lung function and CT metrics. Our results suggest that other neighborhood SES measures, comorbidity burden and ambient pollution burden, do not explain a large component of the adverse association. With such insight, it is important that healthcare providers recognize that individuals residing in segregated or disadvantaged neighborhoods may have often unmeasured contextual factors contributing to disease risk. Furthermore, safeguarding the public's health may include identifying regions and neighborhoods that warrant an allocation of resources to assure a proactive attempt at mitigating health disparities in a manner that clinical interventions alone often cannot. Future interventional studies to reduce the racial disparity in COPD morbidity and severity need to consider the implications and strong associations between racial residential segregation and health for Black communities. ■

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