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Socioeconomic Disparities in Severe Acute Respiratory Syndrome Coronavirus 2 Serological Testing and Positivity in New York City

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Background. We characterized severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) antibody test prevalence and positive test prevalence across New York City (NYC) in order to investigate disparities in testing outcomes by race and socioeconomic status (SES).

Methods. Serologic data were downloaded from the NYC Coronavirus data repository (August 2020–December 2020). Area-level characteristics for NYC neighborhoods were downloaded from United States census data and a socioeconomic vulnerability index was created. Spatial generalized linear mixed models were performed to examine the association between SES and antibody testing and positivity.

Results. The proportion of Hispanic population (posterior median, 0.001 [95% credible interval, 0.0003–0.002]), healthcare workers (0.003 [0.0001–0.006]), essential workers (0.003 [0.001–0.005]), age ≥65 years (0.003 [0.00002–0.006]), and high SES (SES quartile 3 vs 1: 0.034 [0.003–0.062]) were positively associated with antibody tests per 100 000 residents. The White proportion (–0.002 [–0.003 to –0.001]), SES index (quartile 3 vs 1, –0.068 [–0.115 to –0.017]; quartile 4 vs 1, –0.077 [–0.134 to –0.018]) and age ≥65 years (–0.005 [–0.009 to –0.002]) were inversely associated with positive test prevalence (%), whereas the Hispanic (0.004 [0.002–0.006]) and essential worker (0.008 [0.003–0.012]) proportions had positive coefficients.

Conclusions. Disparities in serologic testing and seropositivity exist on SES and race/ethnicity across NYC, indicative of excess coronavirus disease burden in vulnerable and marginalized populations.

Keywords. COVID-19 disease; New York City; SARS-CoV-2; seroprevalence.

Following its first reported case of novel coronavirus disease 2019 (COVID-19) on 1 March 2020 [1], New York City (NYC) quickly became the initial US epicenter of COVID-19. Antibody testing became widely available shortly thereafter in April 2020 and is used to confirm past infection with the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the causative agent of COVID-19 [2]. Antibody testing continues to be conducted among those with or without symptomatology [2, 3]. These test results are useful both at individual and population-level scales, and can be used to measure exposure to SARS-CoV-2 within different geographies and age and populations groups, gain information for contact tracing, and identify possible population sources for monoclonal antibody treatments [3]. However, the longevity of SARS-CoV-2 antibodies after infection remains uncertain, and more definitive quantification of adaptive immunity is needed to inform future testing, vaccination efforts, reinfection risk, and reopening plans.

Within NYC, there have been multiple efforts to quantify seroprevalence, although these have often been restricted to healthcare settings and occurred early in the pandemic. One study in the Northwell Health System studied immunoglobulin G (IgG) antibodies among 46 000 personnel, with testing performed between March and June 2020 [4]. They reported a seroprevalence of 13.7%, which was similar to results of SARS-CoV-2 IgG testing (14.0%) performed randomly across New York State during April 2020 [5]. However, higher seroprevalence estimates were reported in other healthcare populations. Among healthcare workers in the South Bronx, seroprevalence of IgG antibodies was 27% in May 2020 [6]. Subsequent estimates of the general NYC population found similar seroprevalence estimates. In a May–July 2020 sample of 45 367 NYC residents, the prevalence of IgG antibodies was 23.6% [7], while a June–October 2020 study relying on both blood samples to test for IgG antibodies and self-reported antibody test results found a prevalence of 24.3% [8].

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Data from NYC hospital centers early in the pandemic revealed racial disparities in incidence and hospitalizations, with Black patients (1.3-fold) and Hispanic patients (1.5-fold) more likely to test positive, and Black patients 1.89-fold more likely to require hospitalization than White patients [9]. Hispanic patients were also found to be at increased risk for in-hospital mortality (1.84-fold increase) compared to Whites [10]. These findings corroborate both national-level racial variations in mortality [11] and hospitalizations [12], as well as population-level data from NYC [13, 14]. To date, the age-adjusted case, hospitalization, and death rates in NYC are all highest among Black and Hispanic/Latino groups [14]. Moreover, a cross-sectional spatial analysis conducted in April 2020 reported that in areas with lower median income, a greater percentage of individuals who identify as non-White and/or Hispanic/Latino, a greater percentage of essential workers, and a greater percentage of healthcare workers had greater subway use during the early pandemic [15], suggesting a greater potential for SARS-CoV-2 exposure. They also reported that the essential worker population was a main driver of subway use in lower socioeconomic status (SES) areas and communities of color, suggesting an interplay among multiple sociodemographic factors affecting COVID-19 spread.

To date, there have been few studies investigating racial disparities in seroprevalence [7, 16], and those that do exist are not NYC-specific. Among a national sample of dialysis patients, non-Hispanic Black and Hispanic neighborhoods were more likely to be seropositive than patients from non-Hispanic White areas [17]. This finding was also observed in regional areas of the US in both healthcare settings and the general population. Among healthcare workers in the Midwest, Black, Asian, and mixed-race workers were more likely to be seropositive than White workers [18], and a seroprevalence study conducted in Baton Rouge, Louisiana, found that seroprevalence was highest (7.5%) among Black participants [19].

Seroprevalence testing has emerged as a central means of characterizing the burden of SARS-CoV-2 infection and for determining how infections differ by SES and area-level characteristics. To investigate the presence of potential racial and socioeconomic disparities with respect to seroprevalence in NYC, we characterize the spatial and temporal distribution of antibody test prevalence and antibody positivity prevalence and investigate the relationship between community-level characteristics and testing outcomes.

METHODS

Serologic Data

The weekly number of SARS-CoV-2 antibody tests performed and the number of positive test results were downloaded from the NYC Coronavirus (COVID-19) data repository hosted by the NYC Department of Health and Mental Hygiene (DOHMH) from August 2020 through 10 December 2020 [20]. Data were downloaded at the modified zip (postal) code tabulation area (MODZCTA) level, which are areas that approximate an individual's zip code. As used here, ZCTA refers to a person's residence, and not the location where testing occurred. Data in the repository include people of all ages and include any type of serologic test reported to NYC DOHMH. The date of first data release in the repository by MODZCTA was 20 August 2020, which includes data from 5 April–20 August 2020. Cumulative data after 20 August 2020 were downloaded from the NYC Coronavirus data repository weekly.

Socioeconomic Vulnerability Index

An index of socioeconomic vulnerability was created at ZCTA level from 2018 American Community Survey 5-year estimates [21]. This index has been utilized previously [22] to describe area-level SES with respect to SARS-CoV-2 testing and includes data on median household income during the past 12 months, median gross rent, percentage living on income <150% of the poverty line, education, percentage working class, percentage unemployed, and percentage living with >1 occupant per room. The education measure was calculated based from the population aged ≥25 years and is a weighted combination of the population percentage holding a high school degree, only a high school degree, and more than a high school degree, with a greater value indicating higher educational attainment.

The variables used in this analysis differ from the original set [22] through incorporation of the occupants per room measure while removing the median home value to make the index more relevant to NYC and SARS-CoV-2. These variables were then combined using principal component analysis and the first eigenvector was used to create an SES index score for each ZCTA. ZCTAs were classified into quartiles based on this SES score, with a score of 1 corresponding to the lowest SES quartile (ie, lowest resourced) and a score of 4 representing the highest SES quartile (highest resourced).

Covariates

In addition to the variables included in the SES index, the racial (White alone proportion), Hispanic proportion, essential worker proportion, healthcare essential worker proportion, population with insurance coverage, and population >65 years of age for each ZCTA were obtained from 2019 American Community Survey 5-year estimates. The percentage of nonhealthcare essential workers in a ZCTA was defined by the fraction of the civilian employed population ≥16 years employed in agriculture, forestry, fishing and hunting, mining, construction, manufacturing, wholesale trade, retail trade, transportation and warehousing, and utilities, whereas the percentage of healthcare essential workers was defined by healthcare practitioners and healthcare technical occupations, as described previously [15].

Statistical Analysis

Two-week periods of SARS-CoV-2 antibody test prevalence and positivity were compared across SES index quartiles with the spatial distribution of test prevalence and positivity mapped according to ZCTA of residence. Cluster analysis was performed using Anselin Local Moran I over the entire study period to determine clusters of high-test prevalence and positive prevalence. The presence of spatial autocorrelation among outcome variables was investigated with the Moran I test. To account for the spatial structure of our data, a spatial weights matrix was created where each ZCTA polygon was treated as a unique feature. A queen contiguity structure was utilized, where each touching ZCTA was treated as a neighbor, with neighbors considered more closely related than nonneighbors.

Spatial generalized linear mixed models accounting for random effects with a Besag-York-Mollie conditional autoregressive prior were employed to examine the association between SES and antibody testing and positivity. This was performed using the CARBayes package in R [23], which uses Markov chain Monte Carlo simulations to generate model estimates. The model was applied, in turn, to all combinations of predictor variables (SES index, White proportion, Hispanic proportion, healthcare worker proportion, nonessential worker proportion, aged ≥65 years, insurance coverage); 45 000 samples were generated for each model, with a burn-in of 20 000 samples. In the model predicting antibody tests, the population of the ZCTA was used as an offset, whereas the total number of tests was used as an offset for predicting antibody-positive test results. Goodness-of-fit was assessed using the Watanabe-Akaike information criterion (wAIC).

The candidate models were then subject to multimodel inference in order to identify key, common explanatory features. To conduct the multimodel inference, candidate model weights were calculated according to the following formula:

$$w_j = \frac{exp\left[-\frac{1}{2}\ \Delta\ _j\right]}{\sum_{j=1}^{m} exp\left[-\frac{1}{2}\ \Delta\ _j\right]}$$

where $\Delta\ _j = wAIC_j - minwAIC$, and $minwAIC$ is the wAIC value of the model with the lowest wAIC among all candidate models. The smallest subset of models with a total weight $\sum w_j \geq 0.95$ was used for model averaging. The relative importance, or the sum of wAIC weights across models that contain a given predictor variable, as well as the probability this predictor was included in models, were also calculated. All analyses were performed in R version 1.4.1106.

RESULTS

Across all SES quartiles, antibody tests per 100 000 residents in each ZCTA decreased during the study period, whereas test positivity increased (Figure 1). Test prevalence was similar across SES quartiles; on 20 August–3 September 2020 there were 1514 tests per 100 000 residents in the lowest SES areas and 1421 tests per 100 000 residents in the highest SES areas. By 26 November–10 December 2020, there were 693 tests in the lowest SES areas and 745 tests per 100 000 residents in the highest SES

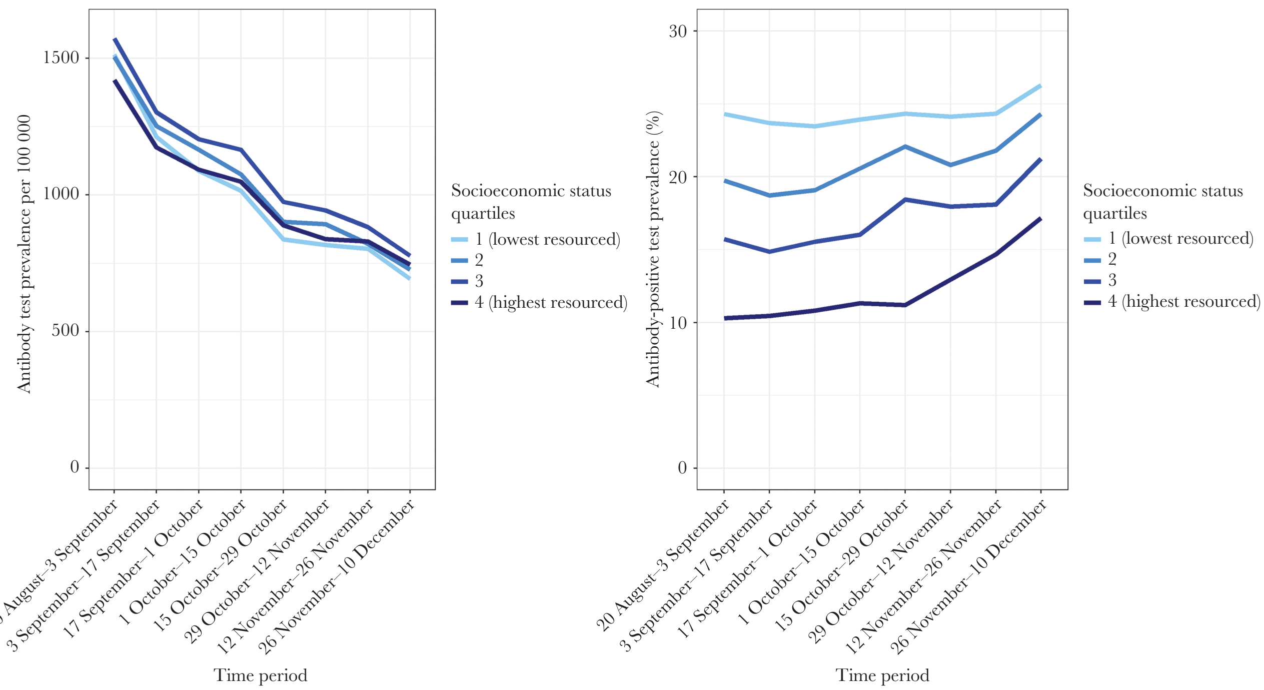

Figure 1. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) antibody tests performed per 100 000 residents (left) and positive prevalence (right) according to socioeconomic status index quartiles.

areas. Additionally, areas of highest SES had the lowest positive test prevalence, while low SES areas had the highest rates of positive test prevalence. From 20 August to 3 September 2020, positive prevalence was 10.30% in the highest SES quartile and 24.31% in the lowest quartile, and by 26 November–10 December 2020, positive prevalence was 17.18% in the highest SES quartile and 26.28% in the lowest SES quartile.

There are 177 MODZCTAs in NYC; the spatial distribution of antibody tests performed (Figure 2A) and positive test prevalence (Figure 2B) are displayed for each 2-week period. The highest rates of testing per 100 000 people in the ZCTA were during 20 August–3 September 2020 and 3 September–17 September 2020, when most testing was performed in Brooklyn, central Queens, and the Bronx. By 26 November–10 December 2020, testing decreased across NYC as a whole, but remained highest in southern Brooklyn, central Queens, and the Bronx. These results stand in contrast with the distribution of antibody positivity rates, which remained high across the entire study period. Notably, positivity was highest in southwestern Brooklyn, central Bronx, and central Queens around Elmhurst. While initially low at the beginning of the study period, positivity increased over time in Staten Island.

The Moran I test statistic for positive testing was 0.58 ($P < .001$) and for tests performed was 0.48 ($P < .001$). Clusters of high testing were present in southern Brooklyn, central Bronx, and central Queens. Similarly, high clusters of positivity were seen in southern Brooklyn, central Bronx, and central Queens.

The results of spatial Poisson regression modeling indicated a good fit for both testing and positivity models across NYC. For testing, model averages of estimates incorporating 95% of the cumulative wAIC produced positive associations (posterior medians with 95% credible intervals [CrIs]) between Hispanic population proportion (0.001 [0.0003–0.002]), healthcare workers (0.003 [0.0001–0.006]), essential workers (0.003 [0.001–0.005]), age ≥65 years (0.003 [0.00002–0.006]), and high SES (SES quartile 3 vs 1: 0.034 [0.003–0.062]) with antibody tests performed per 100 000 residents (Table 1). The individual best fitting model (Table 2) yielded a positive association with SES (quartile 2 vs 1: median, 0.087 [95% CrI, 0.052–0.1352]; quartile 3 vs 1: 0.1421 [0.1047–0.1794]), and Hispanic proportion (0.0029 [0.0010–0.0048]), whereas the second-best fitting model identified positive associations with Hispanic proportion (0.0056 [0.0033–0.0071]), healthcare worker proportion (0.0081 [0.0014–0.0128]), and age ≥65 years (0.0064 [0.0011–0.0112]).

Average estimates (medians with 95% CrIs) for predicting positive tests found that White proportion (−0.002 [−0.003 to −0.001]), SES (quartile 3 vs 1: −0.068 [−0.115 to −0.017]; quartile 4 vs 1: −0.077 [−0.134 to −0.018]), and age ≥65 years (−0.005 [−0.009 to −0.002]) were inversely associated with positivity, whereas Hispanic proportion (0.004 [0.002–0.006]) and essential worker proportion (0.008 [0.003–0.012]) had positive coefficients. The best fitting model (Table 2) predicting positivity identified a positive association with Hispanic proportion (0.0046 [0.0015–0.0074]) and essential worker proportion (0.0127 [0.0024–0.0206]), whereas White proportion (−0.0035 [−0.0055 to −0.0012]) and age ≥65 years (−0.099 [−0.0194 to −0.0030]) showed an inverse association. The second-best fitting model found positive associations with Hispanic proportion (0.0044 [0.0012–0.0072]) and essential worker proportion (0.0095 [0.0038–0.0150]), and negative associations with SES (quartile 3 vs 1: −0.1427 [−0.2142 to −0.0557]; quartile 4 vs 1: −0.1674 [−0.2971 to −0.0504]) and age ≥65 years (−0.0097 [−0.175 to −0.0031]).

Variable importance was similar across model averages for both testing and positivity outcomes (Table 3). In the models of antibody testing for which cumulative wAIC weight ≥95%, insurance coverage and White proportion appeared in the greatest number of models (59 and 58, respectively) and had the highest weights sum (0.52). In the models of positivity for which cumulative wAIC weight ≥95%, Hispanic proportion appeared in the most models (62) and had the highest weights sum (0.67); White proportion (58 models, 0.62) and essential worker proportion (59 models, 0.59) were also important predictors.

DISCUSSION

The findings of this study show that the number of antibody tests performed and positive antibody test results for SARS-CoV-2 varied across NYC by ZCTA, and that SES, proportion of essential workers, the proportion of population aged ≥65 years, and the proportion of the population identifying as Hispanic were important predictors for testing and positivity outcomes. Specifically, areas with higher proportions of Hispanic residents and essential workers were more likely to have increased SARS-CoV-2 testing and seropositivity. Although areas with increased proportions of residents aged ≥65 years experienced more testing, these same areas experienced fewer positive test results. There was a notable trend in SES in which higher SES areas had a lower rate of antibody positivity, despite the absence of a statistically significant relationship between SES and testing.

This analysis corroborates findings identifying racial disparities in COVID-19 cases and deaths, both nationally [11, 24–26] and within NYC [4, 6, 27], underscoring the vulnerability of marginalized, working-class, and lower SES populations. While seroprevalence studies have been performed in NYC using patient or hospital-level data [7, 9, 28], NYC-wide seroprevalence studies are needed to gain a picture of the larger NYC population [7, 8]. Previous serosurveys conducted across NYC [7, 8] reported greatest seroprevalence among Black and Hispanic respondents, people from high-poverty areas, and respondents employed in healthcare or essential worker industries. However, these results were based on a smaller number of surveyed residents. Our results are

Figure 2. Spatial distribution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) antibody tests performed per 100 000 residents (*A*) and positive test prevalence (%) (*B*) during each 2-week interval of the study period.

Table 1. Weighted Model Average Effect Estimates of Antibody Test Prevalence and Positive Test Prevalence

	SARS-CoV-2 Antibody Test Prevalence		SARS-CoV-2 Positive Test Prevalence	
Characteristic	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
White race (%)	0.00039	–0.00033 – 0.00116	**–0.002**	**–0.003 – –0.001**
SES quartile 2 vs 1	0.23	–0.005 – 0.049	–0.014	–0.055 – 0.029
SES quartile 3 vs 1	**0.034**	**0.003–0.062**	**–0.068**	**–0.115 – –0.017**
SES quartile 4 vs 1	0.0298	–0.0013 – 0.0592	**–0.077**	**–0.134 – –0.018**
Hispanic ethnicity (%)	**0.001**	**0.0003–0.002**	**0.004**	**0.002–0.006**
Healthcare worker (%)	**0.003**	**0.0001–0.006**	–0.001	–0.0049 – 0.003
Essential worker (%)	**0.003**	**0.001–0.005**	**0.008**	**0.003–0.012**
Insurance coverage (%)	0.004	–0.001 – 0.009	0.004	–0.002 – 0.01
Age ≥65 y (%)	**0.003**	**0.00002–0.006**	**–0.005**	**–0.009 – –0.002**

Model weights sum to 95% cumulative Watanabe-Akaike information criterion weight. SES quartile 1 represents the lowest-resourced areas, while quartile 4 represents the highest-resourced areas. Bold values denote significant associations.

Abbreviations: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; SES, socioeconomic status.

consistent with what has been previously reported, and are more comprehensive, utilizing city-wide data from a longer time period.

The interplay between SES, essential worker population, and Hispanic composition in New York City is highlighted by examining the distribution of these variables in light of seroprevalence outcomes (Supplementary Figure 1). Regions of high positivity such as southern Brooklyn have a low Hispanic composition, higher rates of essential workers, and average SES index scores (Supplementary Figure 2). This is in contrast to high-positivity areas in the Bronx, which have low SES scores and high Hispanic composition, or those in central Queens, which also have majority Hispanic populations and average SES index scores. However, these 3 regions, in particular, all have a high proportion of essential worker populations, suggesting that this variable is relevant for these 3 communities. The diversity of NYC is indicative of the importance of multiple predictor variables that determine the distribution of antibody testing and positivity in NYC.

One limitation of this analysis is that the dataset used only partially captures antibody testing in NYC, as a number of

Table 2. Summary of the 2 Best Fitting Models for Each Outcome

Model ID	Variable	Posterior Median	95% Credible Interval	wAIC	Weight
SARS-CoV-2 Antibody Test Prevalence					
75	SES quartile 2 vs 1	**0.087**	**0.052–0.1352**	2042.121	0.0231
	SES quartile 3 vs 1	**0.1421**	**0.1047–0.1794**		
	SES quartile 4 vs 1	0.0957	–0.0003 – 0.01474		
	Hispanic ethnicity (%)	**0.0029**	**0.0010–0.0048**		
	Essential worker (%)	0.0042	–0.0008 – 0.0073		
	Insurance coverage (%)	–0.0040	–0.0122 – 0.0045		
84	White race (%)	0.0012	–0.0007 – 0.0027	2042.258	0.0215
	Hispanic ethnicity (%)	**0.0056**	**0.0033–0.0071**		
	Healthcare worker (%)	**0.0081**	**0.0014–0.0128**		
	Age ≥65 y (%)	**0.0064**	**0.0011–0.0112**		
SARS-CoV-2 Positive Test Prevalence					
86	White race (%)	**–0.0035**	**–0.0055 – –0.0012**	1720.93	0.0278
	Hispanic ethnicity (%)	**0.0046**	**0.0015–0.0074**		
	Essential worker (%)	**0.0127**	**0.0024–0.0206**		
	Age ≥65 y (%)	**–0.099**	**–0.0194 – –0.0030**		
119	SES quartile 2 vs 1	–0.0362	–0.1131 – 0.0236	1721.08	0.0257
	SES quartile 3 vs 1	**–0.1427**	**–0.2142 – –0.0557**		
	SES quartile 4 vs 1	**–0.1674**	**–0.2971 – –0.0504**		
	White race (%)	–0.0018	–0.0032 – 0.0004		
	Hispanic ethnicity (%)	**0.0044**	**0.0012–0.0072**		
	Healthcare worker (%)	–0.0002	–0.0079 – 0.0081		
	Essential worker (%)	**0.0095**	**0.0038–0.0150**		
	Age ≥65 y (%)	**–0.0097**	**–0.0175 – –0.0031**		

SES quartile 1 represents the lowest-resourced areas, while quartile 4 represents the highest-resourced areas. Bold values denote significant associations.

Abbreviations: SES, socioeconomic status; wAIC, Watanabe-Akaike information criterion.

Table 3. Relative Importance of Variables From Models With Cumulative Watanabe-Akaike Information Criterion Weight ≥95%

	SARS-CoV-2 Antibody Test Prevalence		SARS-CoV-2 Positive Test Prevalence	
Characteristic	Weights Sum	No. of Models Containing Term (n = 110)	Weights Sum	No. of Models Containing Term (n = 105)
White race	0.52	58	0.62	58
Socioeconomic status index	0.45	56	0.51	55
Hispanic ethnicity (%)	0.50	57	0.67	62
Healthcare worker (%)	0.48	57	0.46	52
Essential worker (%)	0.44	54	0.59	59
Insurance coverage (%)	0.52	59	0.48	57
Age ≥65 y (%)	0.44	55	0.45	54

other efforts were performed at smaller or hospital-specific scales. As such, it is difficult to draw complete conclusions. Similarly, the data reported by NYCDOH are aggregated by ZCTA, limiting our interpretations at the individual level. These data also reflect changes in the accessibility and attitudes toward diagnostic and serologic testing over time. While these tests are currently free and easily available in NYC, this was not the case early in the pandemic, and in spring 2020 diagnostic testing was not encouraged in those with mild/moderate symptoms [24]. This analysis uses American Community Survey data from 2018 and 2019, which may not be reflective of community characteristics during 2020. As this was an ecological study, there are also likely other individual-level factors that may influence seeking SARS-CoV-2 antibody testing that are not accounted for here. It is also possible that populations vulnerable to COVID-19 disease are unable to seek testing due to work restrictions or potential loss of income, or are less likely to seek antibody testing as opposed to diagnostic testing. However, the association between higher SES and reduced positivity found in this study corroborates evidence of increased burden of COVID-19 in vulnerable populations that have been previously documented. This research does not study immune memory over time and does not intend to shed light on what fraction of the population previously exposed to SARS-CoV-2 is protected from reinfection. In trying to understand the risk of reinfection, there needs to be more comprehensive measurement of long-term immunity in the NYC population. However, identifying disparities in the prior burden of SARS-CoV-2 infection can be used to support future vaccination efforts in areas at greatest risk for further SARS-CoV-2 infection and adverse outcomes.

CONCLUSIONS

We found disparities in the burden of cumulative SARS-CoV-2 infection within NYC through the end of 2020, with lower SES communities and essential worker populations at greater risk of seropositivity. Future studies should not only use serological testing in NYC to estimate the extent of COVID-19 disease burden but also investigate why these disparities, such as access to testing, exist. Analyses of seroprevalence at the population level in tandem with research on the longevity of immune memory after infection can also indicate areas at risk of potential reinfection and areas to focus vaccination efforts.

Supplementary Data

Supplementary materials are available at *Open Forum Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

Patient consent statement. This study does not include factors necessitating patient consent as individual-level data were not used.

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All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

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