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Seroprevalence of Severe Acute Respiratory Syndrome Coronavirus 2 Following the Largest Initial Epidemic Wave in the United States: Findings From New York City, 13 May to 21 July 2020

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Background. New York City (NYC) was the US epicenter of the spring 2020 coronavirus disease 2019 (COVID-19) pandemic. We present the seroprevalence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection and correlates of seropositivity immediately after the first wave.

Methods. From a serosurvey of adult NYC residents (13 May to 21 July 2020), we calculated the prevalence of SARS-CoV-2 antibodies stratified by participant demographics, symptom history, health status, and employment industry. We used multivariable regression models to assess associations between participant characteristics and seropositivity.

Results. The seroprevalence among 45 367 participants was 23.6% (95% confidence interval, 23.2%–24.0%). High seroprevalence (>30%) was observed among black and Hispanic individuals, people from high poverty neighborhoods, and people in healthcare or essential worker industry sectors. COVID-19 symptom history was associated with seropositivity (adjusted relative risk, 2.76; 95% confidence interval, 2.65–2.88). Other risk factors included sex, age, race/ethnicity, residential area, employment sector, working outside the home, contact with a COVID-19 case, obesity, and increasing numbers of household members.

Conclusions. Based on a large serosurvey in a single US jurisdiction, we estimate that just under one-quarter of NYC adults were infected in the first few months of the COVID-19 epidemic. Given disparities in infection risk, effective interventions for at-risk groups are needed during ongoing transmission.

Keywords. SARS-CoV-2; seroprevalence; seroepidemiology.

New York City (NYC) was the earliest US epicenter of the coronavirus disease 2019 (COVID-19) pandemic. The first known COVID-19 case in a NYC resident was reported on 1 March 2020. NYC schools closed on 16 March, and all nonessential businesses statewide closed on 22 March when Governor Cuomo announced the "New York State on PAUSE" executive order. However, daily case counts rapidly rose in NYC, reaching a peak of 6365 reported cases (76 per 100 000) on 6 April, and returning to <500 cases (<6 per 100 000) in early June 2020. By 21 July, 219 128 NYC residents had COVID-19 diagnosed by means of nucleic acid testing for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; the virus that causes COVID-19), yielding a cumulative incidence of approximately 2628 per 100 000 for confirmed COVID-19 infections among NYC residents. This estimate did not include people who were infected but who were unable or chose not to seek testing (eg, those with asymptomatic or mildly symptomatic infections), and thus was not reflective of true cumulative COVID-19 incidence.

Compared with studies that use diagnostic tests, seroprevalence surveys can provide more complete estimates of the burden of infection by identifying people who were infected with SARS-CoV-2 but not reported as COVID-19 cases. If antibodies are a marker of total or partial immunity, they may also provide information on the proportion and characteristics of people who remain susceptible to the virus. Early reported seroprevalence estimates for communities in several geographic areas within the United States ranged from 1% to

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20% [1–6]. Most published studies lack details on the characteristics of tested persons useful for determining risk factors for infection and seroconversion. From mid-May through late July 2020, widespread SARS-CoV-2 immunoglobulin G (IgG) antibody testing was offered to all adult NYC residents. We present the seroprevalence of SARS-CoV-2 infection and correlates of seropositivity among a large sample of the city's population.

METHODS

Specimen and Data Collection

Opportunities for no-cost antibody testing were made available for NYC residents aged ≥18 years from 13 May to 21 July 2020. BioReference Laboratories, a large commercial laboratory, conducted specimen collection and testing. SARS-CoV-2 IgG testing was conducted using the Liaison SARS-CoV-2 S1/S2 assay (DiaSorin; 97.6% sensitivity and 99.3% specificity), which had received emergency use authorization from the US Food and Drug Administration [7].

Media, the internet, and local advertisement were used to disseminate information to the public on testing locations and registration procedures. Serosurvey participants made appointments for testing using BioReference Laboratories' online platform, where a survey form was available for them to complete at the time of booking an appointment. Testing sites were set up at city-operated facilities, 1 in each of the 5 boroughs (counties) of NYC. The testing sites were rotated to expand catchment areas, such that 5 specific sites were in operation from 13 May to 2 June and a different set of 5 sites was set up for collections from 26 June to 21 July.

Serosurvey Eligibility and Data Elements

During online self-registration, required screening questions identified persons who may have had very recent infections and were either potentially infectious or had insufficient time to develop antibodies to SARS-CoV-2. Those who self-reported that they tested positive for SARS-CoV-2 with nasal or throat swab samples, or who had fever, new-onset or worsening cough, shortness of breath, or loss of taste (ageusia) or smell (anosmia) in the prior 2 weeks were not eligible for serosurvey participation.

Results of antibody testing were paired with participant characteristics and potential COVID-19 exposures from the self-administered survey. Survey data included the following: demographics, industry and occupation, status of working outside the home during the PAUSE period (23 March to 7 June), exposure to someone with a diagnosis of COVID-19 (within 6 ft for ≥10 minutes, symptoms and symptom-onset date, healthcare seeking and hospitalization for COVID-like illness, a history of a prior SARS-CoV-2 polymerase chain reaction–positive test, housing type and number of household members (measure of crowding), and health status (height, weight, and chronic underlying medical conditions).

Age and address were required for obtaining serology testing; completion of other survey questions was voluntary. Overall, 14.3% of participants (n = 7574) did not complete surveys. Among those who provided survey data, the proportions missing data across 12 categories of questions ranged from 2.7% to 14.0%.

Data Analysis

Participants' zip codes of residence were mapped to neighborhood poverty levels. Neighborhood poverty was defined as the percentage of a zip code's population with household incomes <100% of the federal poverty level, per the 2013–2017 American Community Survey (low poverty, <10%; medium, 10%–19.9%; high, 20%–29.9%; very high, ≥30%) [8].

We collected information on 9 underlying chronic conditions: diabetes, hypertension, heart disease, kidney disease, liver disease, asthma, chronic obstructive pulmonary disease/emphysema/chronic bronchitis, immunosuppressive condition, and immunosuppressive therapy. Reported height and weight were used to calculate participants' body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared); weight status categories were defined as underweight or normal (BMI, <25), overweight (≥25 to <30), obesity (≥30 to <40), and severe obesity (≥40). Participants with implausible weight or height values were excluded from BMI calculation (n = 357).

We collected self-reported information on 11 symptoms of COVID-like illness (CLI) and categorized them into 3 groups: (1) those meeting the current Council of State and Territorial Epidemiologists (CSTE) COVID-19 case definition, which includes cough, shortness of breath/difficulty breathing, loss of taste, loss of smell, or any 2 of chills, fever, headache, diarrhea, vomiting, sore throat, or body aches [9]; (2) those not meeting the CSTE case definition but with chills, fever, headache, diarrhea, vomiting, sore throat, and/or body aches; and (3) those who were asymptomatic (ie, reporting no symptoms).

Industry and occupation data were collected using the questions: "What kind of business or industry do you currently work in?" and "What kind of work do you currently do?" The industry question had dropdown options with the ability to provide a free text response. The Centers for Disease Control and Prevention's National Institute for Occupational Safety and Health Industry and Occupation Computerized Coding System assigned industry codes from 2012 North American Industry Classification System (NAICS) and occupation codes from the 2010 Standard Occupational Classification System [10, 11]. Free text responses that autocoded below a predetermined probability threshold were reviewed by professionally trained coders.

In analyses, we combined participant NAICS sectors to examine seroprevalence for 5 broad categories: (1) healthcare and social assistance (NAICS sector 62); (2) essential workers, considered for our local context to comprise individuals in sectors that were

largely operational during New York on PAUSE (accommodation and food services [sector 722], administrative support and waste management and remediation services [sector 56], construction [sector 23], selected retail trade consisting of grocery and drug stores and pharmacies [sectors 4451–4561], and transportation and warehousing [sectors 48 and 49]); (3) educational services (sector 61); (4) all other NAICS industry sectors; and (5) not working (unemployed, retired, student).

For participants who tested more than once (n = 200), we included test and survey data from the first testing event. Using population denominator estimates, we calculated testing rates per 100 000 NYC residents, stratified by age group, race/ethnicity, borough of residence, and neighborhood poverty level. We calculated the prevalence of SARS-CoV-2 antibodies among those with available survey data (85.7% of all participants), stratified by participant characteristics. Finally, we used robust Poisson regression to examine associations between seropositivity and correlates of interest for the entire sample, as well as subgroups of healthcare workers and essential workers. Significant variables in bivariate analyses ($P < .05$) were included in separate multivariable regression models that adjusted for sex (male or female), age group (18–44, 45–64, or ≥65 years), race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, non-Hispanic Asian/Pacific Islander, or other non-Hispanic races), borough of residence (Bronx, Brooklyn, Manhattan, Queens, or Staten Island), and poverty level (low, medium, high, or very high). The model for employment and seropositivity also adjusted for working outside the home during PAUSE.

Serosurvey data were submitted to the NYC Department of Health and Mental Hygiene (DOHMH) and analyzed using SAS software (version 9.4). The DOHMH Institutional Review Board determined this project to be public health surveillance that does not meet the Office of Human Research Protections definition of human subjects research.

RESULTS

Serosurvey Sample

The seroprevalence among 52 941 serosurvey participants was 24.8%; 7574 did not complete surveys and were excluded from further analysis. While seroprevalence among everyone tested was similar to that among those included in the final analytic sample, participants with missing survey data were older than those with any survey data (44% vs 39% aged ≥45 years) and higher proportions of them lived in Brooklyn, Queens, or the Bronx (vs in Manhattan or Staten Island).

There were 45 367 participants in the final sample, representing an overall testing rate of 680 per 100 000 adult NYC residents. Testing rates varied by key demographics, with substantially higher testing levels among non-Hispanic white individuals (908 per 100 000) and those residing in Staten Island (2512 per 100 000), and very low testing rates among people aged ≥65 years (260 per 100 000), non-Hispanic black individuals (236 per 100 000), and those residing in Brooklyn, the Bronx, and areas of very high poverty (all <460 per 100 000) (Figure 1).

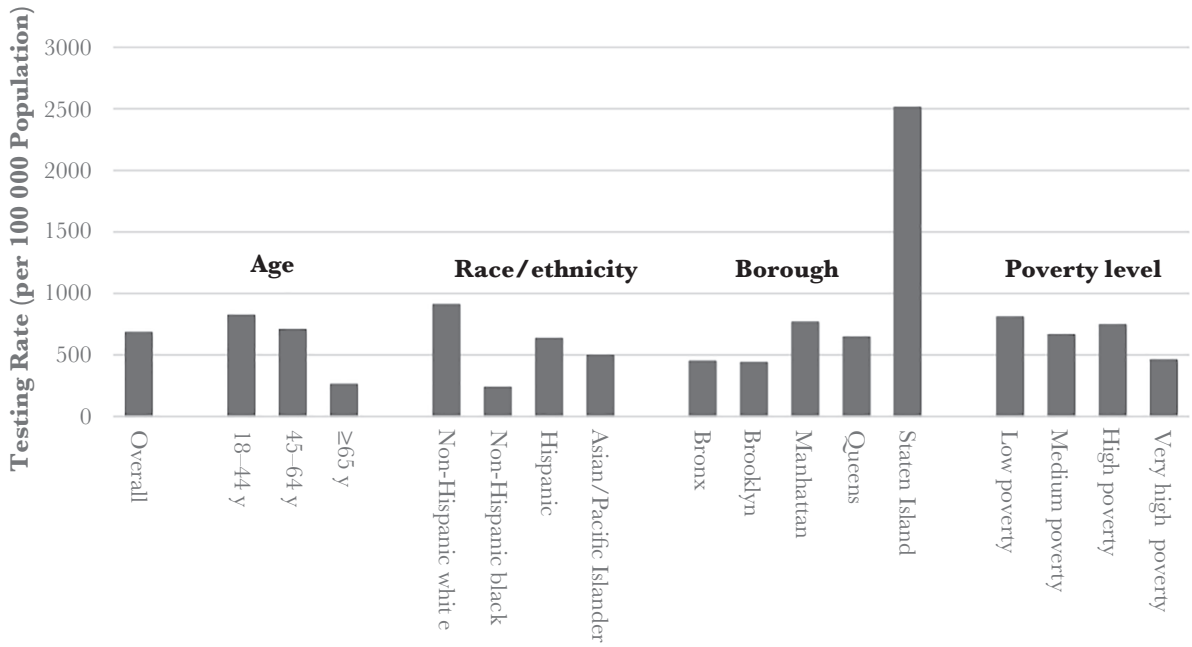


Figure 1. Rate per 100 000 adult New York City residents tested for antibodies to severe acute respiratory syndrome coronavirus 2 from 13 May to 21 July 2020, by age group, race and ethnicity, borough, and neighborhood poverty level.

Seroprevalence Estimates

Of the 45 367 participants in the final sample, 10 725 had antibodies to SARS-CoV-2, yielding an overall seropositivity of 23.6% (95% confidence interval [CI], 23.2%–24.0%). An extrapolation of seroprevalence based on this convenience sample to the population of approximately 6.6 million adult NYC residents would yield an estimate of 1 557 000 individuals with evidence of prior COVID-19 infection. Participant characteristics and associated seroprevalence estimates are shown in Table 1. Approximately one-third of non-Hispanic black and Hispanic participants were seropositive (33.5% and 35.3%, respectively). There was no appreciable variability in seroprevalence according to participant sex at birth, gender identity, sexual orientation, or age. Geographically, the highest seroprevalence was observed among residents in the Bronx (37.0%) and very high-poverty neighborhoods (35.3%). Lower than average seroprevalence (<20%) was noted among residents in Manhattan, Staten Island, and low-poverty neighborhoods.

One-quarter of participants (10 455 of 41 037) with information on comorbid conditions reported ≥1 chronic condition, most commonly hypertension (47%), followed by asthma (38%) and diabetes (18%). Seroprevalence did not vary by chronic disease status (Table 1). Participants who were overweight to severely obese had higher seroprevalence than those in the normal to underweight range (>25% vs 19.7%, respectively). Of participants with information on exposure, 21% reported prolonged, close contact with someone who had tested positive for COVID-19 infection; seroprevalence among this group was substantially higher (35.6%; 95% CI, 34.6%–36.6%) than among participants without exposure to someone with COVID-19 (20.4%; 20.2%–20.9%).

A total of 24 506 (60%) participants reported having had symptoms after 1 January 2020. Of them, the vast majority (87%; 21 239 of 24 506) experienced symptoms meeting the CSTE definition for CLI; roughly one-third were seropositive (34.0%; 7254 of 21 239), compared with approximately 12% of participants who had either no symptoms or symptoms that did not meet the CSTE definition. While participants with selected key symptoms in the 2 weeks before scheduled antibody testing were instructed not to test, 221 with CSTE CLI symptoms during that period did, in fact, get tested; seroprevalence for this group was 17.2%. Table 2 shows increasing seroprevalence estimates with longer intervals between symptom onset and testing, as well as relatively high seroprevalence by healthcare seeking (43.9%) and hospitalization (81.2%) status. Of key isolated symptoms or symptoms, loss of taste or smell was associated with the highest seroprevalence (28.2%). Only 4% of all participants (5% of those with CSTE-defined CLI symptoms and 2% with no or non-CSTE CLI symptoms) reported having had a prior positive COVID-19 diagnostic test; seroprevalence among participants with self-reported histories of confirmed COVID-19 infection was 79.2% (1219 of 1539).

Of 39 502 participants who provided industry and occupation data, 28 549 (72%) were employed at the time of the serosurvey. Seroprevalence by industry category ranged from 19.4% (95% CI, 18.8%–20.1%) to 31.6% (30.3%–33.0%) (Table 1). Approximately one-quarter of participants (26%) worked outside the home during PAUSE: 58% of healthcare workers, 55% of essential workers, 12% in educational services, and 25% of those in other sectors. Seroprevalence was higher among individuals who reported working outside the home during the time of New York on PAUSE (27.4%; 95% CI, 26.6%–28.3%) than among those who did not (22.2%; 21.8%–22.7%). Figure 2 shows a detailed breakdown of seroprevalence by industry within the healthcare and social assistance and essential worker categories.

Correlates of Seropositivity

Of 13 variables we examined, only 2—underlying conditions and type of housing—were not significantly associated with seropositivity in bivariate analyses (Table 3). Male sex, age 44–64 years, nonwhite race/ethnicity, living in a borough other than Manhattan or Staten Island, and living in neighborhoods with high or very high poverty levels were significantly associated with seropositivity in a multivariable regression model that included sex, age group, race/ethnicity, borough, and poverty. Adjusting for these 5 demographic variables in separate multivariable models, the following factors were associated with seropositivity: employment in a healthcare or essential worker category, or being unemployed at the time of the serosurvey; working outside the home during PAUSE; having close contact with someone with COVID-19; having had CLI symptoms (the factor most strongly associated with seropositivity; adjusted relative risk. 2.76; 95% CI, 2.65–2.88); being overweight, obese, or severely obese; and increasing numbers of household members.

For healthcare workers and essential workers specifically, correlates of seropositivity were largely the same as those observed for the entire serosurvey sample. Key differences for healthcare workers were that seropositivity was not associated with sex or living in very high poverty. For essential workers, seropositivity was not associated with age; living in Brooklyn, the Bronx, Manhattan, or Staten Island; or working outside the home during PAUSE.

DISCUSSION

From the largest SARS-CoV-2 serosurvey in a single US jurisdiction to date, we estimate that the number of persons infected with SARS-CoV-2 may have been as much as 7 times higher than the number of reported cases in the first 5 months of the pandemic. Almost one-quarter of people tested had evidence of acquired SARS-CoV-2 in the initial period of the pandemic. Amid continued SARS-CoV-2 transmission, layered

Table 1. Characteristics of Participants and Proportions With Antibodies to Severe Acute Respiratory Syndrome Coronavirus 2

Characteristic	Participants, No. (%)	Seroprevalence	
		No. Positive	% Positive (95% CI)
All participants	45 367 (100)	10 725	23.6 (23.2–24.0)
Race/ethnicity (n = 42 158)			
Non-Hispanic white	20 368 (48)	3269	16.0 (15.5–16.6)
Non-Hispanic black	3467 (8)	1162	33.5 (32.0–35.1)
Hispanic	11 629 (28)	4106	35.3 (34.4–36.2)
Non-Hispanic Asian/Pacific-Islander	5028 (12)	1017	20.2 (19.1–21.4)
Non-Hispanic other/multiple races	1666 (4)	392	23.5 (21.5–25.6)
Sex at birth (n = 44 164)			
Male	20 519 (46)	4964	24.2 (23.6–24.8)
Female	23 645 (54)	5445	23.0 (22.5–23.6)
Gender identity (n = 43 831)			
Man	20 285 (46)	4895	24.1 (23.5–24.7)
Woman	23 286 (53)	5356	23.0 (22.5–23.5)
Transgender/gender nonconforming	260 (1)	47	18.1 (13.9–23.2)
Sexual orientation (n = 41 525)			
Straight	37 115 (89)	8676	23.4 (22.9–23.8)
Lesbian, gay, bisexual, queer, and other nonheterosexual orientations	4410 (11)	895	20.3 (19.1–21.5)
Age group (n = 45 367)			
18–44 y	27 667 (61)	6411	23.2 (22.7–23.7)
45–64 y	14 457 (32)	3617	25.0 (24.3–25.7)
≥65 y	3243 (7)	697	21.5 (20.1–22.9)
Borough of residence (n = 45 367)			
Bronx	4828 (11)	1789	37.0 (35.7–38.4)
Brooklyn	8766 (19)	2038	23.2 (22.4–24.1)
Manhattan	10 674 (24)	2076	19.4 (18.7–20.2)
Queens	11 736 (26)	3334	28.4 (27.6–29.2)
Staten Island	9363 (21)	1488	15.9 (15.2–16.6)
Poverty level (n = 45 363)			
Low (<10% below FPL)	10 961 (24)	1933	17.6 (16.9–18.4)
Medium (10% to <20% below FPL)	18 030 (40)	4262	23.6 (23.0–24.3)
High (20% to <30% below FPL)	11 708 (26)	2882	24.6 (23.8–25.4)
Very high (≥30% below FPL)	4664 (10)	1647	35.3 (33.9–36.7)
Symptoms (n = 40 880)			
Meeting CSTE definition[a]	21 329 (52)	7254	34.0 (33.4–34.6)
Symptomatic but not meeting CSTE definition	3177 (8)	359	11.3 (10.2–12.4)
Asymptomatic	16 374 (40)	2062	12.6 (12.1–13.1)
Employment sector (n = 39 502)			
Healthcare and social assistance	4297 (11)	1289	30.0 (28.6–31.4)
Educational services	4220 (11)	854	20.2 (19.0–21.5)
Essential worker[b]	5205 (13)	1644	31.6 (30.3–33.0)
Other industries	14 827 (37)	2878	19.4 (18.8–20.1)
Not working	10 953 (28)	2605	23.8 (23.0–24.6)
Worked outside home (23 March to 6 June 2020) (n = 40 581)			
Yes	10 768 (26)	2953	27.4 (26.6–28.3)
No	29 813 (73)	6630	22.2 (21.8–22.7)
Underlying medical conditions (n = 41 037)			
Yes[c]	10 455 (25)	2538	24.3 (23.5–25.1)
No	30 582 (75)	7173	23.4 (23.0–23.9)
Weight status (n = 39 031)			
Underweight/normal weight	16 896 (43)	3324	19.7 (19.1–20.3)
Overweight	13 139 (34)	3303	25.1 (24.4–25.9)
Obese	7883 (20)	2213	28.1 (27.1–29.1)
Severely obese	1113 (3)	295	26.5 (24.0–29.2)

Table 1. Continued

Characteristic	Participants, No. (%)	Seroprevalence	
		No. Positive	% Positive (95% CI)
Close proximity to person with COVID-19 (n = 40 260)[d]			
Yes	8464 (21)	3011	35.6 (34.6–36.6)
No/don't know	31 796 (79)	6500	20.4 (20.0–20.9)
Self-reported prior positive COVID-19 diagnosis test (n = 40 568)			
Yes	1539 (4)	1219	79.2 (77.1–81.2)
No/don't know	39 029 (96)	8355	21.4 (21.0–21.8)
Housing type (n = 39 746)			
Single family	14 932 (38)	3454	23.1 (22.5–23.8)
Multiunit housing	24 814 (62)	5852	23.6 (23.1–24.1)
No. in household (n = 39 535)			
1 (living alone)	6963 (18)	1252	18.0 (17.1–18.9)
2	12 416 (31)	2381	19.2 (18.5–19.9)
3	7635 (19)	1868	24.5 (23.5–25.4)
4	6680 (17)	1799	26.9 (25.9–28.0)
5	3253 (8)	1054	32.4 (30.8–34.0)
6	1393 (4)	493	35.4 (32.9–37.9)
7	593 (1)	187	31.5 (27.9–35.4)
≥8	602 (2)	259	43.0 (39.1–47.0)

Abbreviations: CI, confidence interval; COVID-19, coronavirus disease 2019; CSTE, Council for State and Territorial Epidemiologists; FPL, federal poverty level.

[a]CSTE definition: cough, shortness of breath/difficulty breathing, loss of taste, loss of smell, or any 2 of the following captured in the serosurvey: chills, fever, headache, diarrhea, vomiting, sore throat, or body aches.

[b]Includes workers considered essential during the period of New York on PAUSE (23 March to 7 June 2020): those in food services, administrative and support and waste management and remediation services, construction, retail trade (grocery, pharmacy/drug stores only), and transportation and warehousing.

[c]Includes ≥1 of the following: diabetes, hypertension, chronic heart disease, chronic kidney disease, chronic liver disease, asthma, chronic obstructive pulmonary disease/emphysema/chronic bronchitis, immunosuppressive condition (eg, human immunodeficiency virus, autoimmune disease), and immunosuppressive therapy (eg, cancer treatment).

[d]Exposure within 6 ft for >10 minutes to a person with diagnosed COVID-19.

interventions, including rigorous and extensive monitoring, testing, contact tracing, promotion of individual prevention measures (eg, face coverings, social distancing, frequent handwashing), and community restrictions on indoor activities, have been implemented as an attempt to slow its spread.

Geographic and demographic characteristics of serosurvey participants with SARS-CoV-2 antibody tracked with the epidemiology of reported COVID-19 cases in NYC [12]. The highest seroprevalence was observed among black and Hispanic people, and those living in Queens and the Bronx. Communities with higher poverty levels were disproportionately affected; more than one-third of participants living in zip codes where >30% of the population was living below the federal poverty level had antibodies to the SARS-CoV-2 virus.

Elevated risks of testing seropositive persisted for these groups after accounting for other individual characteristics. Drivers of COVID-19 risk in urban areas include population density, transportation, employment with frequent public contact, crowded housing, and other socioeconomic and environmental factors [13–15]. Differential exposure to various forms of structural oppression, including structural racism—centuries of racist policies and discriminatory practices across institutions, including government agencies, and society—also negatively affects the overall health and well-being of black and Hispanic individuals [16]. While interventions have aimed to optimize access and convenience to diagnostic testing and support services (eg, venues for isolation/quarantine), these interventions have not halted ongoing transmission. More research on the complex interplay of underlying social, environmental, economic, and structural inequities is needed to understand increased risk of COVID-19 in communities of color in NYC and elsewhere, in order to effect interventions and policies that can reduce observed health disparities.

Our survey collected information on industry and occupation. Knowledge about risks for infection among people in various work settings is important for planning, implementing, evaluating, and improving prevention interventions. Studies have reported on seroprevalence among staff in healthcare settings [17, 18], which was found to be as high as 31% in 1 NYC medical center in late spring-summer 2020 [18]. We report a similar prevalence among serosurvey participants who worked in the healthcare and social assistance sector (30%), and further found 45%–50% seropositivity among subsets in nursing home or home healthcare services. Essential workers with exposure to the public, as defined for this study, had seropositivity

Table 2. Seroprevalence Among Participants With Symptoms Meeting Council for State and Territorial Epidemiologists Clinical Case Definition

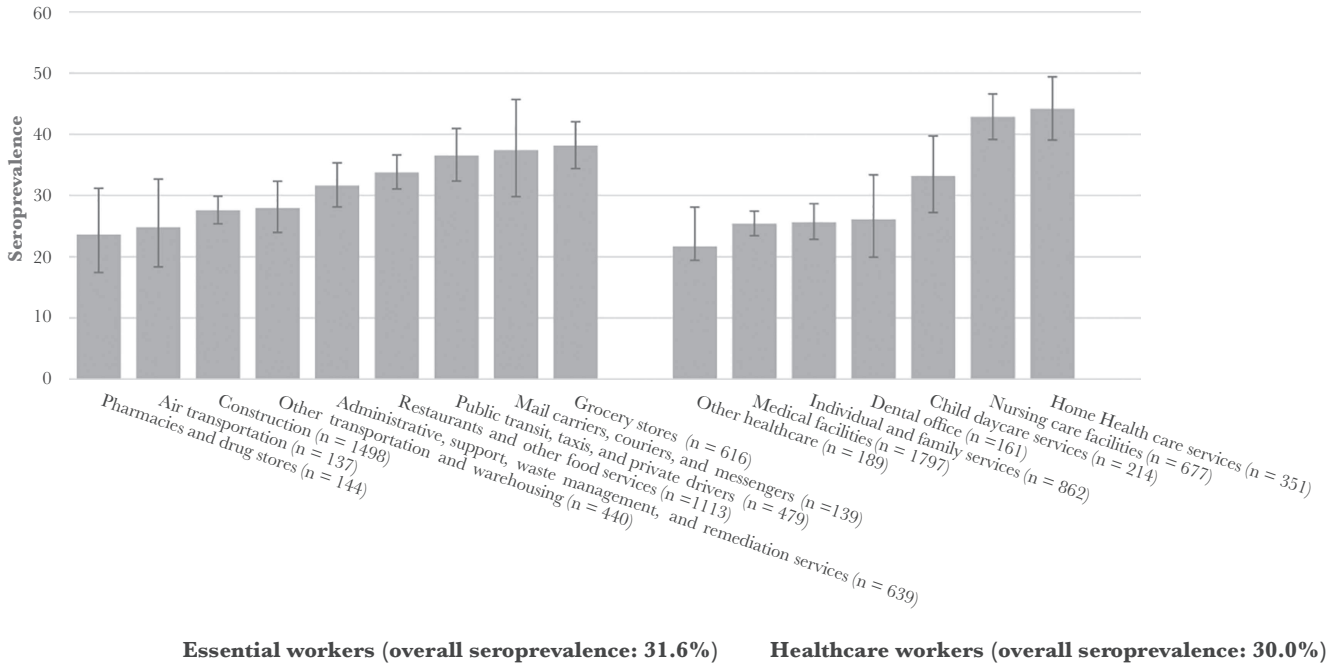
Symptoms	Participants Tested, No. (%)	Seroprevalence, No. (%) Positive
All	21 329 (100)	7254 (34.0)
Time from symptom onset, d		
0–14	221 (1)	38 (17.2)
15–28	385 (2)	84 (21.8)
29–42	817 (4)	302 (37.0)
≥43	12 832 (60)	5582 (43.5)
Don't know/missing	7074 (33)	1248 (17.6)
Sought healthcare		
Yes	4764 (22)	2347 (49.3)
No	16 565 (78)	4907 (29.6)
Hospitalized		
Yes	181 (1)	147 (81.2)
No	21 148 (99)	7107 (33.6)
Symptom**s**		
Cough (n = 9630)		
Cough only	178 (2)	32 (18.0)
Cough plus other symptoms[a]	9452 (98)	4452 (47.1)
Shortness of breath (n = 11 785)		
Shortness of breath only	675 (6)	71 (10.5)
Shortness of breath plus other symptoms[a]	11 110 (94)	3747 (33.7)
New loss of smell and/or taste (n = 13 224)		
New loss of smell/taste only	500 (4)	141 (28.2)
New loss of smell/taste plus other symptoms[a]	12 724 (96)	5915 (46.5)

[a]Symptoms include ≥1 of the following: cough, shortness of breath/difficulty breathing, loss of taste, loss of smell, chills, fever, headache, diarrhea, vomiting, sore throat, and body aches.

>30%. Our data support vaccine prioritization for workers in industries of accommodations and food services (eg, restaurant workers), transportation and warehousing (eg, public transit, drivers, postal workers, couriers), retail trade (eg, grocery store workers), and those of other essential workers [19]. Until vaccines are widely available and taken, preventive measures to reduce workplace exposures to SARS-CoV-2 should continue to be emphasized [20].

While it has been suggested that 40%–45% of SARS-CoV-2 infections are asymptomatic [21], we found that 21% of serosurvey participants with antibodies to SARS-CoV-2 did not report a COVID-19–like illness. More than 1 in 10 participants with either no symptoms or symptoms not meeting the clinical case definition for COVID-19 were seropositive. While symptoms meeting the CSTE COVID-19 definition captured three-quarters of antibody-positive people and had suboptimal prediction (positive predictive value, 34%), there was an almost 3-fold risk of testing seropositive among participants with CSTE-consistent symptoms, compared to those without such symptoms. Among the CSTE symptoms, loss of taste and/or smell as sole symptom(s) was more predictive of seropositivity than only fever or only cough. Our experience with investigating SARS-CoV-2 clusters has revealed presentations with few and mild symptoms, making early recognition and control a significant challenge.

There are limitations to our analysis. We used a convenience sample, therefore it is possible that people who sought out testing perceived themselves to have been more likely to have been exposed to SARS-CoV-2; indeed, 60% of participants reported a history of CLI symptoms. A considerably biased sample could overestimate seroprevalence. On the other hand, lower representation of certain subgroups with higher infection rates—such as black and Hispanic individuals—could underestimate true seroprevalence. However, our overall seroprevalence estimate was very similar to published estimates derived from a number of other NYC-based convenience samples during roughly the same time period; these include a New York State serosurvey of almost 6000 NYC residents recruited at grocery stores (seroprevalence, 22.7%) [6], testing of residual clinical specimens obtained from 2 commercial laboratories that serve NYC (ranging from 17.6% to 23.2%, depending on the week of collection between April and July) [22, 23], and a serosurvey of NYC first responders and public safety personnel (seroprevalence, 22.5%) [24].



Other health care includes offices of other health practitioners, optometrists, chiropractors, community food and housing, rehabilitation services

Figure 2. Seroprevalence among participants working in healthcare, social assistance, and essential worker settings.

Our estimate also aligns well with the overall percentage of NYC residents who tested positive for SARS-CoV-2 antibodies across NYC healthcare facilities, which was roughly 20% as of the third week of July 2020 [25]. Population-based, representative serosurveys will yield the most accurate measures of seroprevalence for NYC; results from a series of citywide population-based serosurvey being conducted by the DOHMH since early in the pandemic are forthcoming. The earliest of those serosurveys (June–October 2020) has found a weighted seroprevalence of 24.3%, a very similar estimate to ours [26].

Complete survey data were missing for approximately 15% of records and there were additional, partially missing data across survey fields. We chose not to impute missing values, as we could not know the source and/or extent of any biases related to missing data and did not want to risk magnifying them. We did not pretest questions and there was the potential for issues related to comprehension. For example, approximately 20% of participants who reported having tested positive with a swab or saliva test for SARS-CoV-2 did not have detectable antibodies. Some people, particularly those with mild or clinically inapparent infection, may not develop detectable serum antibodies after infection or have antibodies that persist [27–31], perhaps accounting for no IgG antibody detection by the time the serosurvey took place. It is possible, though, that some of these participants reported having received a diagnostic test, and not necessarily a positive test result, leading to our misclassification of their prior diagnosis.

Seroprevalence studies are useful for understanding the true prevalence of infection. We found that after the first several months of the pandemic, a substantial proportion of people in NYC had evidence of prior infection with SARS-CoV-2. However, it was less than what would lead to the herd immunity needed to prevent future large outbreaks of COVID-19, which is estimated to be as much as 70%, assuming that (1) the basic reproductive number for SARS-CoV-2 is between 2 and 3.5 and (2) infection confers long-lasting immunity [32–34].

While population-based samples that are not subject to selection bias are ideal, convenience samples such as ours can be informative when they more fully characterize tested individuals and their risk exposures. Some strengths of this seroprevalence survey are that it captured descriptors such as sexual orientation and gender identity and included large samples from racial/ethnic minority populations. Estimates of seroprevalence can be combined with other measures of disease burden, such as diagnoses and mortality rates, to monitor trends and geographic distribution over time, identify hotspots and at-risk populations needing special attention, and ultimately aid in assessing the effectiveness of interventions.

Table 3. Factors Associated With Seropositivity

Factor	Participants With SARS-CoV-2 Antibodies, No./Total (%)		Relative Risk (95% CI)	
	Exposure	No Exposure	Bivariate	Multivariable[a]
Sex at birth				
Male	4964/20 519 (24.2)	15 555/20 519 (75.8)	1.00 (Reference)	1.00 (Reference)
Female	5445/23 645 (23.0)	18 200/23 645 (77.0)	0.95 (.92–.98)	0.94 (.90–.97)[b]
Age group, y				
18–44	6411/27 667 (23.2)	21 256/27 667 (76.8)	1.00 (Reference)	1.00 (Reference)
45–64	3617/14 457 (25.0)	10 840/14 457 (75.0)	1.08 (1.04–1.12)	1.08 (1.04–1.12)[b]
≥65	697/3243 (21.5)	2546/3243 (78.5)	0.93 (.87–0.99)	0.98 (.92–1.05)
Race/ethnicity				
Non-Hispanic white	3269/20 368 (16.0)	17 099/20 368 (84.0)	1.00 (Reference)	1.00 (Reference)
Non-Hispanic black	1162/3467 (33.5)	2305/3467 (66.5)	2.09 (1.97–2.21)	1.83 (1.72–1.94)[b]
Hispanic	4106/11 629 (35.3)	7523/11 629 (64.7)	2.20 (2.11–2.29)	1.84 (1.76–1.92)[b]
Non-Hispanic Asian/Pacific Islander	1107/5028 (20.2)	4011/5028 (79.8)	1.26 (1.18–1.34)	1.13 (1.06–1.21)[b]
Non-Hispanic other/multiple races	392/1666 (23.5)	1274/1666 (76.5)	1.47 (1.34–1.61)	1.31 (1.19–1.44)[b]
Borough of residence				
Bronx	1789/4828 (37.1)	3039/4828 (62.9)	2.33 (2.20–2.47)	1.43 (1.33–1.54)[b]
Brooklyn	2038/8766 (23.2)	6728/8766 (76.8)	1.46 (1.38–1.55)	1.19 (1.11–1.27)[b]
Manhattan	2076/10 674 (19.4)	8598/10 674 (80.6)	1.22 (1.15–1.30)	1.02 (.96–1.09)
Queens	3334/11 736 (28.4)	8402/11 736 (71.6)	1.69 (1.79–1.89)	1.52 (1.43–1.62)[b]
Staten Island	1488/9363 (15.9)	7875/9363 (84.1)	1.00 (Reference)	1.00 (Reference)
Neighborhood poverty level				
Low poverty (<10% below FPL)	1933/10 961 (17.6)	9028/10 961 (82.4)	1.00 (Reference)	1.00 (Reference)
Medium (10% to <20% below FPL)	4262/18 030 (23.6)	13 768/18 030 (76.4)	1.34 (1.28–1.41)	1.03 (.98–1.08)
High (20% to <30% below FPL)	2882/11 708 (24.6)	8826/11 708 (75.4)	1.40 (1.33–1.47)	1.24 (1.17–1.31)[b]
Very high (≥30%) below FPL)	1647/4664 (35.3)	3017/4664 (64.7)	2.00 (1.89–2.12)	1.31 (1.22–1.41)[b]
Employment sector				
Educational services	854/4220 (20.2)	3366/4220 (79.8)	1.04 (.97–1.12)	1.05 (.98–1.13)
Essential workers[c]	1644/5205 (31.6)	3561/5205 (68.4)	1.63 (1.55–1.71)	1.33 (1.26–1.40)[b]
Healthcare and social assistance	1289/4297 (30.0)	3008/4297 (70.0)	1.55 (1.46–1.63)	1.35 (1.27–1.43)[b]
Other industries	2878/14 827 (19.4)	11 949/14 827 (80.6)	1.00 (Reference)	1.00 (Reference)
Not working	2605/10 953 (23.8)	8348/10 953 (76.2)	1.23 (1.17–1.28)	1.16 (1.10–1.21)[b]
Worked outside home (23 March to 7 June 2020)				
No	6630/29 813 (22.2)	23 183/29 813 (77.8)	1.00 (Reference)	1.00 (Reference)
Yes	2953/10 768 (27.4)	7815/10 768 (72.6)	1.23 (1.19–1.28)	1.14 (1.10–1.19)[b]
Close proximity to person with COVID-19[d]				
No	6500/31 796 (20.4)	25 296/31 796 (79.6)	1.00 (Reference)	1.00 (Reference)
Yes	3011/8464 (35.6)	5453/8464 (64.4)	1.74 (1.68–1.80)	1.65 (1.59–1.71)[b]
Symptoms meeting CSTE definition[e]				
No	2421/19 551 (12.4)	17 130/19 551 (87.6)	1.00 (Reference)	1.00 (Reference)
Yes	7254/21 329 (34.0)	14 075/21 329 (66.0)	2.75 (2.63–2.86)	2.76 (2.65–2.88)[b]
Weight status				
Underweight/normal	3324/16 896 (19.7)	13 572/16 896 (80.3)	1.00 (Reference)	1.00 (Reference)
Overweight	3303/13 139 (25.1)	9836/13 139 (74.9)	1.28 (1.22–1.33)	1.13 (1.08–1.18)[b]
Obese	2213/7883 (28.1)	5670/7883 (71.9)	1.43 (1.36–1.50)	1.21 (1.15–1.28)[b]
Severe obesity	295/1113 (26.5)	818/1113 (73.5)	1.35 (1.22–1.49)	1.14 (1.03–1.27)[f]
Underlying medical conditions[g]				
No	7173/30 582 (23.5)	23 409/30 582 (76.5)	1.00 (Reference)	NI
Yes	2538/10 455 (24.3)	7917/10 455 (75.7)	1.03 (.99–1.08)	NI

Table 3. Continued

Factor	Participants With SARS-CoV-2 Antibodies, No./Total (%)		Relative Risk (95% CI)	
	Exposure	No Exposure	Bivariate	Multivariable[a]
Type of housing				
Single-family home	3454/14 932 (23.1)	11 478/14 932 (76.9)	1.00 (Reference)	NI
Multiunit dwelling	5852/24 814 (23.6)	18 962/24 814 (76.4)	1.02 (.98–1.06)	NI
No. of household members			1.14 (1.13–1.16)	1.11 (1.10–1.12)[b]

Abbreviations: CI, confidence interval; NI, not included in multivariable model; COVID-19, coronavirus disease 2019; CSTE, Council for State and Territorial Epidemiologists; FPL, federal poverty level; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

[a]Model for sex at birth adjusted for age group, race/ethnicity, borough of residence, and neighborhood poverty level; model for age group adjusted for sex at birth, race/ethnicity, borough of residence, and neighborhood poverty level; model for race/ethnicity adjusted for sex at birth, age group, borough of residence, and neighborhood poverty level; model for borough of residence adjusted for sex at birth, age group, race/ethnicity, and neighborhood poverty level; model for neighborhood poverty level adjusted for sex at birth, age group, race/ethnicity, and borough of residence; employment model adjusted for sex at birth, age group, race/ethnicity, borough of residence, and neighborhood poverty level, and working outside the home during the period of PAUSE (23 March to 7 June 2020); all other models adjusted for sex at birth, age group, race/ethnicity, borough of residence, and neighborhood poverty level.

[b]$P < .001$.

[c]Includes workers considered essential during the period of New York on PAUSE (23 March to 7 June 2020): those in food services, administrative and support and waste management and remediation services, construction, retail trade (grocery, pharmacy/drug stores only), transportation, and warehousing.

[d]Exposure within 6 ft for >10 minutes to a person with diagnosed COVID-19.

[e]CSTE definition includes cough, shortness of breath/difficulty breathing, loss of taste, or loss of smell, or any 2 of the following captured in the serosurvey: chills, fever, headache, diarrhea, vomiting, sore throat, or body aches.

[f]$P < .05$.

[g]Includes ≥1 of the following: diabetes, hypertension, chronic heart disease, chronic kidney disease, chronic liver disease, asthma, chronic obstructive pulmonary disease/emphysema/chronic bronchitis, immunosuppressive condition (eg, human immunodeficiency virus, autoimmune disease), immunosuppressive therapy (eg, cancer treatment)

Notes

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