OBJECTIVE: Coronavirus disease 2019 (COVID-19) has disproportionally affected communities of color. We aimed to determine what factors are associated with COVID-19 testing and test positivity in an underrepresented, understudied, and underreported (U3) population of mothers.

METHODS: This study included 2996 middle-aged mothers of the Boston Birth Cohort (a sample of predominantly urban, low-income, Black and Hispanic mothers) who were enrolled shortly after they gave birth and followed onward at the Boston Medical Center. COVID-19 testing and test positivity were defined by the SARS-CoV-2 nucleic acid test. Two-probit Heckman selection models were performed to identify factors associated with test positivity while accounting for potential selection associated with COVID testing.

RESULTS: The mean (SD) age of study mothers was 41.9 (±7.7) years. In the sample, 1741 (58.1%) and 667 (22.3%) mothers were self-identified as Black and Hispanic, respectively. A total of 396 mothers had COVID-19 testing and of those, 95 mothers tested positive from March 2020 to February 2021. Among a multitude of factors examined, factors associated with the probability of being tested were obesity (RR = 1.27; 95% confidence interval (CI): 1.08–1.49); and presence of preexisting chronic medical conditions including hypertension, asthma, stroke, and other comorbidities (coronary heart disease, chronic kidney disease, and sickle cell disease) with a corresponding RR = 1.40 (95% CI: 1.23–1.60); 1.29 (95% CI: 1.11–1.50); 1.44 (95% CI: 1.23–1.68); and 1.37 (95% CI: 1.12–1.67), respectively. Factors associated with higher incident risk of a positive COVID-19 test were body mass index, birthplace outside of the USA, and being without a college-level education.

CONCLUSIONS: This study demonstrated the intersectionality of obesity and social factors in modulating incident risk of COVID-19 in this sample of US Black and Hispanic middle-aged mothers. Methodologically, our findings underscore the importance of accounting for potential selection bias in COVID-19 testing in order to obtain unbiased estimates of COVID-19 infection.
infection and severity [3, 5, 7, 8], in addition to lower socioeconomic status, overcrowded living environments, poverty, and employment in essential frontline jobs where social distancing is challenging. (https://read.oecd-ilibrary.org/view/?ref=137_137245-8sah eqv0k&title=What-is-the-effect-of-the-COVID-19-pandemic-on-immigrants-and-their-children%3F) [4, 5]. Importantly, the obesity epidemic and its associated morbidities such as diabetes and hypertension have persisted in the US and disproportionately affected low-income minority populations [9, 10]. Although some studies have examined race and ethnicity disparities in testing, incidence, and outcomes of COVID-19 [3, 4, 11], data are limited about what factors are associated with excess COVID-19 infection rate in communities of color, especially, among those understudied about what factors are associated with excess COVID-19 infection rate in communities of color, especially, among those understudied.

likely to be Black (Supplementary Table 1). The study protocol was approved by the Institutional Review Boards of BMC and Johns Hopkins Bloomberg School of Public Health. Written informed consent was obtained from all study participants.

METHODS

Study participants

Study participants were mothers enrolled in the Boston Birth Cohort (BBC) [15], a predominantly urban, low-income, minority population in Boston, Massachusetts, one of the large cities seriously affected by COVID-19. As of July 19, 2021, there have been 71,399 cases of COVID-19 and 1,395 associated deaths in Boston [16]. Detailed information on participant enrollment has been described previously [15]. Briefly, mother–infant pairs were enrolled 24 to 72 h after delivery. After obtaining written informed consent, trained research staff interviewed mothers using a standardized questionnaire to obtain socio-demographic, lifestyle, diet, and environmental and health variables [17]. This study only focused on mothers. Maternal date of birth was abstracted from medical records. This study included those mothers who continued their medical care at the Boston Medical Center (BMC) and consented to participate in the postnatal follow-up study. A detailed description of the postnatal follow-up was described previously [18]. In brief, to minimize study participants’ burden, we tried to align research study visits with study participants’ clinical appointments. Maternal postnatal clinical data, including weight, height, and chronic clinical diseases were extracted from mothers’ medical records. As shown in the study flowchart (Supplementary Fig. 1), as of October 2020, data were collected from 3394 BBC mother–child pairs who have continued to receive primary care at BMC. Of those, 398 mothers were removed because their written informed consent was expired (n = 98) or because of being enrolled twice due to repeated pregnancies (n = 300). The final sample for this study included 2996 mothers who were enrolled for postnatal follow-up during 2004–2019. Compared to the entire BBC sample, mothers included in the current study were similar to the overall cohort, except that they were more likely to be Black (Supplementary Table 1). The study protocol was approved by the Institutional Review Boards of BMC and Johns Hopkins Bloomberg School of Public Health. Written informed consent was obtained from all study participants.

Socio-demographic variables

At study enrollment, each mother completed a questionnaire to assess race/ethnicity, education, nativity, and smoking during pregnancy, along with their medical and reproductive history. For this study, race/ethnicity was grouped into Black (i.e., Black and not Hispanic), Hispanic, and Other. Educational attainment was grouped into “high school and below” or “college and above.” Nativity was categorized into “US-born” or “foreign-born.”

Adiposity measurements

Weight and height at index prepregnancy were obtained by in-person questionnaire. Weight and height during follow-up measured from medical staff at clinic visits were extracted from the mothers’ electronic medical records (EMRs). Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared. Overweight and obesity were defined as BMI ≥ 25 kg/m² but < 30 kg/m² and BMI ≥ 30 kg/m², respectively [19]. In this report, we used BMI at the last clinical visit before the COVID-19 pandemic. The median (inter-quartile range) timeframe of the last maternal visit before the defined onset of the pandemic was 2.7 (1.6–6.5) years.

Ascertaining of chronic medical conditions during follow-up

Preexisting chronic medical conditions (diabetes mellitus, hypertension, coronary heart disease (CHD), chronic kidney disease (CKD), stroke, asthma, and sickle cell disease (SCD)) were abstracted from the mothers’ EMRs and identified by the International Classification of Diseases (ICD) ninth revision, Clinical Modification (ICD-9-CM) and tenth revision (ICD-10-CM) codes. Diabetes was diagnosed based on ICD-9-CM: 250 and ICD-10-CM: E10–E11 [20]. Chronic hypertension was diagnosed based on ICD-9-CM: 401–404; ICD-10-CM: I10–I11 [20, 21]. CHD was defined as ICD-9-CM: 410–414 and 429.2; or ICD-10-CM: I20–I25 [20]. Stroke was defined as ICD-9-CM: 430 to 438; and ICD-10-CM: 160 to 169 [20]. CKD was defined based on ICD codes: ICD-9-CM 585.0–585.6, 585.9; and ICD-10-CM: N18.1–N18.5, N18.9. Asthma was defined as ICD-9-CM of 493 and ICD-10-CM of J45 [22]. SCD was defined as ICD-9-CM of 282.60–282.64, 282.68–282.69, 282.80–282.82; and ICD-10-CM of D75.70, D75.71, D75.2, D75.4, and D75.8. Due to a small number of CHD, CKD, and SCD, we combined these three conditions as “Other comorbidity.” Finally, a composite comorbidity score was calculated by counting the number of chronic medical conditions (range from 0–6) and further categorized into 0, 1, and 2–6.

COVID-19 testing status and test result

COVID-19 test receipt and result were identified through continuous EMR (including emergency room, inpatient, outpatient, and laboratory data) surveillance of the study mothers at BMC (the medical home for the study mothers) from March 2020 through February 2021. Laboratory result of the nucleic acid test for SARS-CoV-2 (the virus that causes COVID-19) was categorized as “tested” vs. “non-tested;” those tested were further grouped into “tested positive” vs. “tested negative.” For the study period, the majority of COVID-19 tests were conducted at BMC, which served as one of the major COVID-19 testing sites in Boston, MA. In rare cases when testing occurred outside of BMC, EMR surveillance documented COVID testing both at BMC and outside facilities.

Statistical analyses

Demographic and clinical variables are presented as mean (SD) for continuous variables and frequencies (proportions) for categorical variables across COVID-19 testing and test positivity status. Unadjusted P values for group comparisons (i.e., tested vs non-tested or test negative vs test positive) were calculated using the Chi-square test for categorical variables and by t test for continuous variables. Pearson correlation was
performed to examine the correlation between BMI at baseline (index prepregnancy) and follow-up. Since BMI at baseline and follow-up were highly correlated \((p = 0.67, \text{Supplementary Fig. 2})\), only BMI or obesity status at follow-up were included in subsequent analyses.

First, probit regression was applied to capture the characteristics of COVID-19 testing in univariate and fully adjusted models, respectively. The fully adjusted models included age groups, race/ethnicity, nativity, education, obesity status, diabetes, hypertension, asthma, stroke, and other comorbidities. Risk ratios (RRs) and corresponding 95% confidence intervals (CIs) were reported. Next, we further examined risk factors for COVID-19 test positivity. Since COVID-19 testing was not performed at random due to limited test availability and prioritization, particularly in the early phases of the pandemic, two-probit Heckman (two-step) selection models were applied to obtain unbiased estimates using sampleSelection R package \([23]\). In step 1, we specified a probit regression for the probability of COVID-19 testing. In step 2, we specified a probit regression for COVID-19 test positivity, conditioned on the probability of testing.

The proportion of COVID-19 test positivity in subgroup was calculated among mothers with testing results. To address the effect of smoking, we performed a sensitivity analysis including maternal smoking status at baseline (during index pregnancy) in the model, because data on smoking at follow-up were not available. In addition, given that this study included data collected from March 2020 to February 2021, a wide timeframe, during which potentially different exposure risks over time across subgroup populations were present, we conducted a sensitivity analysis with additional adjustment for indicators of COVID-19 pandemic time periods specific to Boston, MA (lockdown on March 24; phase 1 reopening on May 18, 2020; phase 2 reopening on June 8, 2020; phase 3 reopening on July 13, 2020; and return to phase 2 on December 16, 2020). All statistical analyses were performed using RStudio (version 3.6.2, R-Tools Technology Inc., ON, CANADA). A two-sided \(P\) value < 0.05 was considered to be statistically significant.

### RESULTS

#### Characteristics of the study population

The review of EMR data revealed that 13.2% of the study sample \((n = 396)\) received a COVID-19 test from March 1, 2020 to Feb 14, 2021. Nearly 24% of those tested \((n = 95)\) were positive for COVID-19. Table 1 presents the study population’s demographic characteristics at enrollment and clinical variables at the last visit during follow-up. More than half of the sample \((n = 1741)\) were self-identified as Black \((58.1\%)\) and 667 \((22.3\%)\) as Hispanic. About 51.9% of the mothers had at least one diagnosed chronic medical condition (hypertension, diabetes, asthma, stroke, CHD, CKD, SCD). Compared to non-tested mothers, tested mothers had higher BMI and included a higher proportion with obesity as well as higher rates of hypertension, stroke, asthma, and other chronic medical conditions at follow-up. Participants with a positive COVID-19 test were more likely to be foreign-born compared with participants with a negative COVID-19 test \((82.1\% \text{ vs } 44.5\%)\).

#### Factors associated with COVID-19 testing

Being older than age 45 years was associated with a 21% lower risk ratio \((\text{RR} = 0.79, \text{95\% CI: } 0.66–0.94)\) for COVID-19 testing, after adjustment for covariates, compared to mothers younger than age 35 years (Table 2). In addition, compared to mothers with normal weight, there was a dose–response association between being overweight \((1.18 \text{ times (95\% CI: } 1.00–1.40)\) or having obesity \((1.27 \text{ times (95\% CI: } 1.08–1.49)\) and being tested. Of note, the association between being overweight and being tested was marginal, \(p = 0.058\); but the association between having obesity and being tested was significant, \(p = 0.004\). Chronic medical conditions including diabetes, hypertension, stroke, asthma, and other comorbidities (CHD, CKD, SCD) were each associated with an increased probability of seeking COVID-19 testing, RR \((\text{95\% CI): } 1.28 (1.09–1.51), 1.47 (1.31–1.66), 1.46 (1.27–1.68), 1.54 (1.32–1.79), \text{and } 1.56 (1.29–1.89)\), respectively, compared to mothers without these conditions. These associations remained statistically significant in the fully adjusted model, except for diabetes (Table 2).

#### Sensitivity analysis

Since we collected data on maternal smoking status at baseline (i.e., during index pregnancy), but not in follow-up, we included maternal smoking status during pregnancy in the Heckman selection model. We observed a 17 percentage point reduction in COVID-19 test positivity in smoker, but smoking was not associated with COVID-19 testing (Supplementary Table 2). Moreover, the number of COVID-19 testing and test positivity in our study population were parallel with the time period of COVID-19 pandemic in Boston, MA (Supplementary Fig. 3). To adjust for potentially different exposure risks over time, the indicators of COVID-19 pandemic time periods specific to Boston were included in the Heckman model, though similar results were obtained (Supplementary Table 3).

#### DISCUSSION

This study is unique in respect to the specific efforts taken to account for selection bias in testing and to apply a closer lens to the intersectionality of obesity, chronic diseases, and social factors to examine COVID-19 testing and test positivity among middle-aged Black and Hispanic mothers. This study fills a research gap in the literature related to advancing our understanding of factors affecting incident risk for COVID-19 in understudied, underrepresented, and underreported (U3) populations. Specifically, in this cohort of primarily Black and Hispanic middle-aged, low-income mothers, we identified factors associated with COVID-19 testing and test positivity, including a joint influence of biomedical and social risk factors. We found that mother who were younger, with obesity, and who had preexisting chronic medical conditions were more likely to obtain a COVID-19 test—findings that are consistent with selective testing based on clinical indications or exposure, in the absence of universal testing. After accounting for potential selection bias regarding testing, we identified risk factors for COVID-19 test positivity: lower educational attainment, foreign-born status, and higher BMI. Mothers with 2 or co-existing chronic medical conditions, such as diabetes, hypertension, CHD, CKD, SCD.
stroke, asthma, or SCD also had a tendency of higher incidence of COVID-19 test positivity, although the association was not significant.

Consistent with previous studies that revealed detrimental effects of obesity on COVID-19 susceptibility [3, 7, 12], our study found that higher BMI was associated with COVID-19 test positivity, independent of other comorbidities. Given the fact that the prevalence of obesity exceeds 42% in the US [24], where the total number of COVID-19 cases is one of the highest in the world [25], these data emphasize that obesity and the COVID-19 pandemic converged into a co-epidemic. Although the potential underlying mechanisms related to obesity and COVID test positivity are outside the scope of this study, previous studies have documented that individuals with obesity experience sustained low-grade systemic inflammation [26], and impaired adaptive immune response to infection [27]. In addition, obesity is characterized by increased activation of the systemic and local adipose tissue renin–angiotensin–aldosterone system [28], which may link to SARS-CoV-2 to enter into adipocytes [29]. Therefore, an appropriate and timely multidisciplinary approach is needed to address this evident co-epidemic.

Our study also revealed the important role of social factors. We found that mothers without a college education were at increased risk of COVID-19 test positivity. Although we did not have specific information about their occupations, we speculate that mothers with higher education may be less likely to be employed in service-related jobs and more likely to engage in remote work, which may have reduced their potential for virus exposure. Consistent with previous research that reported a higher risk of COVID-19 infection among immigrants [13, 14], our data demonstrated a significantly increased risk of COVID-19 test positivity among foreign-born mothers independent of the effects of age, education, obesity, and chronic medical conditions. Although the exact mechanism underlying this association is unknown, we hypothesize that this is likely

Table 1. Characteristics of the study population by COVID-19 testing status and test positivity status among those tested.

| Characteristics          | Total sample | Tested | p          | Non-tested | Tested | p          |
|--------------------------|--------------|--------|------------|------------|--------|------------|
|                          | N            |        |            |            |        |            |
| Age group (yrs)          | 2600         | 396    | 0.042      | 301        | 95     | 0.002      |
| ≤35                      | 502 (19.3)   | 97 (24.5) |          | 84 (27.9)  | 13 (13.7)|          |
| 35–45                    | 1193 (45.9)  | 177 (44.7) |          | 121 (40.2) | 56 (58.9)|          |
| >45                      | 905 (34.8)   | 122 (30.8) |          | 96 (31.9)  | 26 (27.4)|          |
| Education with college   | 938 (36.1)   | 142 (35.9) | 0.978     | 117 (38.9) | 25 (26.3)| 0.036      |
| Race/ethnicity           |              |        | 0.413      |            |        | 0.243      |
| Other                    | 520 (20.0)   | 68 (17.2)  |          | 54 (17.9)  | 14 (14.7)|          |
| Black                    | 1505 (57.9)  | 236 (59.6) |          | 183 (60.8) | 53 (55.8)|          |
| Hispanic                 | 575 (22.1)   | 92 (23.2)  |          | 64 (21.3)  | 28 (29.5)|          |
| Foreign-born             | 1606 (61.8)  | 212 (53.5) | 0.002     | 134 (44.5) | 78 (82.1)| <0.001     |
| Smokera                  | 484 (18.6)   | 73 (18.4)  | 0.986     | 69 (22.9)  | 4 (4.2)  | <0.001     |
| PBMI (kg/m²)             | 26.5 (6.5)   | 28.4 (8.2) | <0.001    | 28.3 (8.4) | 28.7 (7.2)| 0.627      |
| BMI category (kg/m²)     |              |        | 0.214      |            |        |            |
| <25                      | 1275 (49.0)  | 160 (40.4) |          | 128 (42.5) | 32 (33.7)|          |
| 25–29.9                  | 739 (28.4)   | 105 (26.5) |          | 74 (24.6)  | 31 (32.6)|          |
| ≥30                      | 586 (22.5)   | 131 (33.1) |          | 99 (32.9)  | 32 (33.7)|          |
| BMI (kg/m²)              | 30.2 (7.3)   | 32.2 (8.0) | <0.001    | 31.9 (8.2) | 33.1 (7.4)| 0.181      |
| BMI category (kg/m²)     |              |        | 0.056      |            |        |            |
| <25                      | 639 (24.6)   | 65 (16.4)  |          | 51 (16.9)  | 14 (14.7)|          |
| 25–29.9                  | 808 (31.1)   | 113 (28.5) |          | 94 (31.2)  | 19 (20.0)|          |
| ≥30                      | 1153 (44.3)  | 218 (55.1) |          | 156 (51.8) | 62 (65.3)|          |
| Diabetes                 | 289 (11.1)   | 65 (16.4)  | 0.003     | 46 (15.3)  | 19 (20.0)| 0.356      |
| Hypertension             | 742 (28.5)   | 178 (44.9) | <0.001    | 139 (46.2) | 39 (41.1)| 0.449      |
| Stroke                   | 301 (11.6)   | 88 (22.2)  | <0.001    | 68 (22.6)  | 20 (21.1)| 0.863      |
| Asthma                   | 400 (15.4)   | 105 (26.5) | <0.001    | 80 (26.6)  | 25 (26.3)| 1.000      |
| Other comorbidities      | 169 (8.5)    | 53 (13.4)  | <0.001    | 44 (14.6)  | 9 (9.5)  | 0.267      |
| Comorbidity score        |              |        | <0.001     |            |        | 0.371      |
| 0                        | 1325 (51.0)  | 117 (29.5) |          | 85 (28.2)  | 32 (33.7)|          |
| 1                        | 797 (30.7)   | 135 (34.1) |          | 108 (35.9) | 27 (28.4)|          |
| 2+                       | 478 (18.4)   | 144 (36.4) |          | 108 (35.9) | 36 (37.9)|          |

Unadjusted p values for group comparisons (i.e., tested vs non-tested or test negative vs test positive) were calculated using the Chi-square test for categorical variables and by t test for continuous variables. PBMI prepregnancy BMI at index pregnancy.

*Smoker represents smoking status during index pregnancy.

stroke, asthma, or SCD also had a tendency of higher incidence of COVID-19 test positivity, although the association was not significant.

Consistent with previous studies that revealed detrimental effects of obesity on COVID-19 susceptibility [3, 7, 12], our study found that higher BMI was associated with COVID-19 test positivity, independent of other comorbidities. Given the fact that the prevalence of obesity exceeds 42% in the US [24], where the total number of COVID-19 cases is one of the highest in the world [25], these data emphasize that obesity and the COVID-19 pandemic converged into a co-epidemic. Although the potential underlying mechanisms related to obesity and COVID test positivity are outside the scope of this study, previous studies have documented that individuals with obesity experience sustained low-grade systemic inflammation [26], and impaired adaptive immune response to infection [27]. In addition, obesity is characterized by increased activation of the systemic and local adipose tissue renin–angiotensin–aldosterone system [28], which may link to SARS-CoV-2 to enter into adipocytes [29]. Therefore, an appropriate and timely multidisciplinary approach is needed to address this evident co-epidemic.

Our study also revealed the important role of social factors. We found that mothers without a college education were at increased risk of COVID-19 test positivity. Although we did not have specific information about their occupations, we speculate that mothers with higher education may be less likely to be employed in service-related jobs and more likely to engage in remote work, which may have reduced their potential for virus exposure. Consistent with previous research that reported a higher risk of COVID-19 infection among immigrants [13, 14], our data demonstrated a significantly increased risk of COVID-19 test positivity among foreign-born mothers independent of the effects of age, education, obesity, and chronic medical conditions. Although the exact mechanism underlying this association is unknown, we hypothesize that this is likely
Table 2. Socio-demographic and medical factors associated with COVID-19 testing.

| Factors                      | Univariate model | Full model |
|------------------------------|------------------|------------|
|                              | RR 95% CI        | p          | RR 95% CI | p   |
| Age groups                   |                  |            |            |
| 36–45 yr vs. ≤35 yr          | 0.87 (0.75–1.00) | 0.055      | 0.87 (0.75–1.02) | 0.081 |
| >45 yr vs. ≤35 yr            | 0.82 (0.70–0.96) | 0.015      | 0.79 (0.66–0.94) | 0.008 |
| Race/Ethnicity               |                  |            |            |
| Black vs Other               | 1.10 (0.95–1.28) | 0.213      | 1.00 (0.86–1.18) | 0.956 |
| Hispanic vs Other            | 1.11 (0.93–1.33) | 0.237      | 1.13 (0.94–1.37) | 0.193 |
| Nativity (foreign-born vs US-born) | 0.83 (0.74–0.94) | 0.002      | 0.91 (0.80–1.04) | 0.170 |
| Education (college vs lower) | 0.99 (0.88–1.12) | 0.933      | 1.02 (0.90–1.15) | 0.779 |
| Obesity status               |                  |            |            |
| Overweight vs normal weight  | 1.18 (1.00–1.39) | 0.052      | 1.18 (1.00–1.40) | 0.058 |
| Obesity vs normal weight     | 1.39 (1.19–1.62) | 0.000      | 1.27 (1.08–1.49) | 0.004 |
| Diabetes (yes vs no)         | 1.28 (1.09–1.51) | 0.003      | 1.06 (0.88–1.26) | 0.537 |
| Hypertension (yes vs no)     | 1.47 (1.31–1.66) | 0.000      | 1.40 (1.23–1.60) | 0.000 |
| Asthma (yes vs no)           | 1.46 (1.27–1.68) | 0.000      | 1.29 (1.11–1.50) | 0.001 |
| Stroke (yes vs no)           | 1.54 (1.32–1.79) | 0.000      | 1.44 (1.23–1.68) | 0.000 |
| Other comorbidities (yes vs no) | 1.56 (1.29–1.89) | 0.000      | 1.37 (1.12–1.67) | 0.002 |

The full model included age groups, race/ethnicity, nativity, education, obesity status, diabetes, hypertension, asthma, stroke, and other comorbidities. CI confidence interval, RR risk ratio, US United States.

*Other comorbidities include coronary heart disease, chronic kidney disease, and sickle cell disease.

Table 3. Socio-demographic and medical factors associated with COVID-19 positivity, after accounting for potential selection bias for being tested.

| Factor                        | Step 1 | Step 2 |
|-------------------------------|--------|--------|
|                               | Coef   | SE     | p     |
|                               | Coef   | SE     | p     |
| Age group:                    |        |        |       |
| 36–45 yr vs. ≤35 yr           | –0.14  | 0.08   | 0.082 |
| >45 yr vs. ≤35 yr             | –0.24  | 0.09   | 0.008 |
| Race/Ethnicity                |        |        |       |
| Black vs Other                | 0.00   | 0.08   | 0.956 |
| Hispanic vs Other             | 0.13   | 0.10   | 0.193 |
| Education (college vs lower)  | 0.02   | 0.06   | 0.780 |
| Nativity (foreign-born vs US-born) | –0.09 | 0.07   | 0.172 |
| Native language (English vs Other) | 0.00  | 0.12   | 0.990 |
| Overweight vs. normal weight  | 0.17   | 0.09   | 0.058 |
| Obesity vs normal weight      | 0.24   | 0.08   | 0.004 |
| Diabetes (yes vs no)          | 0.06   | 0.09   | 0.536 |
| Hypertension (yes vs no)      | 0.34   | 0.07   | 0.000 |
| Asthma (yes vs no)            | 0.25   | 0.08   | 0.001 |
| Stroke (yes vs. no)           | 0.36   | 0.08   | 0.000 |
| Other comorbidities (yes vs no) | 0.31  | 0.10   | 0.002 |
| BMI (per 5 kg/m² change)      | 0.03   | 0.01   | 0.018 |
| Comorbidity score             |        |        |       |
| 1 vs 0                        | 0.04   | 0.07   | 0.569 |
| 2+ vs 0                       | 0.18   | 0.12   | 0.144 |

Two-probit Heckman selection models were used to control for potential selection bias. Other comorbidity included coronary heart disease, chronic kidney disease, and Sickle cell disease. Step 1 (selection model) included age group, race/ethnicity, education, nativity, obesity status, diabetes, hypertension, asthma, stroke, other comorbidities; Step 2 (outcome model) included age groups, race/ethnicity, education, nativity, BMI, and comorbidities score categories. BMI body mass index, Coef coefficient, SE standard error, US United States.
due to a combination of social risk factors of COVID-19 exposure and infection shown to be prevalent in foreign-born populations, such as exposure to overcrowded living environments, higher incidence of poverty, and employment in high exposure/contact jobs (i.e., to provide essential services such as health care, or at essential businesses like grocery stores, etc.) where social distancing is challenging (https://read.oecd-ilibrary.org/view/?ref=137_137245-8saheqv0k3&title=What-is-the-impact-of-the-COVID-19-pandemic-on-immigrants-and-their-children%3F). Notably, both education and nativity were not associated with receipt of COVID-19 testing. This finding is consistent with the testing prioritization that was mainly based on clinical indicators, not socio-demographic factors. This study, by accounting for selection for testing, revealed that socio-demographic factors were associated with increased risk of COVID-19 infection.

Previous observational studies have shown conflicting results about the association between chronic medical conditions and COVID-19 infection, perhaps in part due to selectivity of COVID-19 testing [3, 13, 14]. For example, a study conducted by Gu et al. [3], documented an important influence of selection bias in association between chronic medical conditions and COVID-19 susceptibility. Consistently, our results showed that these same medical conditions, except for diabetes, were significantly associated with COVID-19 testing, which is consistent with testing prioritization of individuals with chronic medical conditions. In our study, when selection factors for COVID-19 testing were corrected by using Heckman selection models, we found a trend but statistically insignificant association between number of chronic medical conditions and COVID-19 test positivity. Interestingly, our data showed that older mothers were less likely to get tested compared with younger mothers. This may be due to experiencing more COVID-related symptoms as a result of providing more caregiving for children and older family members, or needing to work more (as testing could be required by their employers). However, mother’s age was not associated with COVID-19 test positivity, further suggesting the need to take into account selectivity of testing sampling in these analyses. Notably, our study showed a lower risk of COVID-19 test positivity in smokers. Although similar findings have been found in previous studies [3, 8, 13], this result should be considered carefully due to the smoking status in our study reflecting the status during index pregnancy, not current.

Considered together, our findings have important public health implication: First, our study contributes to an understanding of the risk factors for COVID-19 incident risk among a population of low-income middle-age Black and Hispanic mothers. While most COVID-19 studies have focused on high-risk older populations, middle-age mothers are critical to families as caregivers and to society as active contributors to the workforce and economy. Second, our findings support that the obesity pandemic has significantly intersected with and exacerbated the COVID-19 pandemic. Third, our findings illustrate the need for increased attention to the health of immigrant and refugee communities, who are at risk for many preventable health conditions in addition to COVID-19. Finally, our findings indicate that the interplay of biomedical and social factors contributes to and amplifies the impacts of the COVID-19 pandemic, a potential new source of health disparities among the most disenfranchised segments of the US population.

Our study has the following limitations. The study population is a predominantly urban, low-income, primarily Black and Hispanic cohort in Boston, MA. Thus, caution is needed when assessing the generalizability of the findings to other populations with different characteristics. The sample size of our study, particularly those...
with a positive COVID-19 test, was modest. As a result, we were not able to perform detailed analyses on severity of COVID-19 cases. We did not have information on individual occupations, exposures, or living conditions, nor did we have patient-reported data regarding their decisions to seek testing including symptomatic illness. Our findings remain to be confirmed in larger studies. In addition, we may miss some testing done in other settings outside of BMC and cannot exclude the possibility that some non-tested mothers would have tested positive for COVID-19. Therefore, our findings might be underestimated and real-world findings could, in fact, be even stronger.

The strengths of this study are its prospective cohort design with a well-defined population and baseline characteristics before the pandemic; the availability of data on individual-level COVID-19 testing and test positivity; and a rich database of potential biomedical and social determinants of COVID-19 from a predominantly US urban, low-income cohort of Black and Hispanic mothers, which included a high proportion of immigrants [30]. More importantly, we hope this study will stimulate more research along these lines, with a goal to better understand and improve health and well-being and reduce health disparities among U3 populations now and in the future.

CONCLUSIONS

This study demonstrated the intersectionality of obesity and social factors in modulating incident risk of COVID-19 in this sample of US low-income Black and Hispanic middle-aged mothers. The findings further underscore the methodological importance of accounting for test selection factors in order to better estimate risk factors of COVID-19 infection.

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AUTHOR CONTRIBUTIONS
GW, DMF, JD, and XW: Designed and conceptualized the study, drafted and revised the manuscript. CP, GM, SR: Acquired data, reviewed and revised the manuscript. GW, XH, and HJ: Performed the analyses. XH, NS, KSK, HS, JS, TLC, BZ: Interpreted the results, reviewed and revised the manuscript. GW and XW take full responsibility for the analyses and content presented in this manuscript. All authors approved the final version.

COMPETING INTERESTS
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