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Racial/Ethnic, Biomedical, and Sociodemographic Risk Factors for COVID-19 Positivity and Hospitalization in the San Francisco Bay Area

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Abstract

Background The COVID-19 pandemic has uncovered clinically meaningful racial/ethnic disparities in COVID-19-related health outcomes. Current understanding of the basis for such an observation remains incomplete, with both biomedical and social/contextual variables proposed as potential factors.

Purpose Using a logistic regression model, we examined the relative contributions ofrace/ethnicity, biomedical, and socioeconomic factors to COVID-19 test positivity and hospitalizationrates in a large academic health care system in the San Francisco Bay Area prior tothe advent of vaccination and other pharmaceutical interventions for COVID-19.

Results Whereas socioeconomic factors, particularly those contributing to increased social vulnerability, were associated with test positivity for COVID-19, biomedical factors and disease co-morbidities were the major factors associated with increased risk of COVID-19 hospitalization. Hispanic individuals had a higher rate of COVID-19 positivity, while Asian persons had higher rates of COVID-19 hospitalization. The excess hospitalization risk attributed to Asian race was not explained by differences in the examined biomedical or sociodemographic variables. Diabetes was an important risk factor for COVID-19 hospitalization, particularly among Asian patients, for whom diabetes tended to be more frequently undiagnosed and higher in severity.

Conclusion We observed that biomedical, racial/ethnic, and socioeconomic factors all contributed in varying but distinct ways to COVID-19 test positivity and hospitalization rates in a large, multi-racial, socioeconomically diverse metropolitan area of the United States. The impact of a number of these factors differed according to race/ethnicity. Improving overall COVID-19 health outcomes and addressing racial and ethnic disparities in COVID-19 outcomes will likely require a comprehensive approach that incorporates strategies that target both individual-specific and group contextual factors.

Keywords Asian · COVID-19 · Racial health disparities · Risk factors · Diabetes mellitus

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Introduction

Pandemics can be viewed as "natural experiments" that are able to yield insights into disease transmission dynamics, population health status and equity, and health care system responsiveness because they are discrete, novel, and large exogenous health shocks that are unfettered by pre-existing differences and structural inequalities associated with already prevalent diseases. The COVID-19 pandemic presents such a unique opportunity at a time when detailed molecular pathogen diagnostics and healthcare data can be captured and analyzed in near-real time, providing not only insights into disease outcomes and dynamics but also data-driven decision support for pandemic mitigation resource allocation and policymaking. In this regard, the COVID-19 pandemic stands in contrast to the 1918 influenza pandemic, during which World War I-associated disruptions and the nascent state of the public health surveillance infrastructure impeded consistent collection of morbidity and mortality statistics across the United States. Notwithstanding such limitations, available data from the 1918 influenza pandemic indicated health disparities in influenza outcomes for Black Americans versus White Americans, presaging those being observed in the present-day COVID-19 pandemic and suggesting that health inequity across racial (and socioeconomic) lines has a long-standing history and remains a continuing concern in the United States well into the 21st century.

During the 1918 influenza pandemic, compared to the White population in the United States, Black Americans exhibited lower influenza incidence and morbidity rates but higher mortality rates [1, 2]. It has been hypothesized that structural racism, rather than race per se, was largely responsible for racial health disparities observed during the 1918 influenza pandemic. For example, if the living and social conditions experienced by Black Americans of that era had predisposed them to acquiring infection with earlier, less virulent strains of influenza, then any partial immunity that may have been acquired might have lowered attack rates of the subsequent 1918 influenza strain among Black persons [3]. For those Black individuals who did become infected with the 1918 influenza strain, it might also be argued that their observed higher mortality rates could have been in part due to Black Americans' generally poorer health status and reduced access to equitable health care, both of which may stem from the consequences of structural racism.

In the intervening century since the 1918 influenza pandemic, the United States (U.S.) population has become more multi-racial. In this same period, the racial health disparities have continued to persist, now across multiple racial and ethnic groups. During the COVID-19 pandemic in the United States, Black and Hispanic individuals have tested positive for COVID-19 at higher rates than White individuals [4–7], and COVID-19-related hospitalizations and deaths have disproportionately affected American Indian, Asian, Black, and Hispanic persons [8–11]. Despite recognition of racial health disparities dating back more than a century, the extent and the mechanisms that fuel these disparities are not well understood.

In order to better understand the relative contributions of biomedical, racial/ethnic, and socioeconomic factors to health disparities in the COVID-19 pandemic, we examined COVID-19 test positivity and hospitalization rates in a racially, ethnically, and socioeconomically diverse region of the United States, the San Francisco Bay Area. The Bay Area is of particular value for conducting such a study due to its pluralistic racial and ethnic composition and the region's relative decoupling of race/ethnicity and socioeconomic status as compared to many other U.S. metropolitan areas, particularly for Asian individuals [8].

We previously reported an initial analysis of racial and ethnic differences in COVID-19 test positivity and hospitalization rates among patients of a large, multi-hospital, multi-clinic academic health care system in the San Francisco Bay Area [8]. In that study, no significant association between race and the frequency of COVID-19 testing was observed in that, for all racial and ethnic groups, the absolute deviations of the distribution of those undergoing testing differed from the overall UCSF patient pool distribution by no more than 3%. We found that higher social vulnerability, Black race, and Hispanic ethnicity were associated with a higher rate of COVID-19 positivity, whereas COVID-19 hospitalization and morbidity rates were highest among Asian patients. As members of the largest racial group, White persons tallied large numbers of COVID-19-related deaths, but Hispanic individuals who died of COVID-19 had the lowest mean age and thus suffered the highest average number of years of life lost.

In the present study, we conduct a more detailed analysis of the contributing factors to COVID-19 positivity and hospitalization among the same study population, specifically extending our investigation to include a number of individual-specific biomedical correlates of health. We present logistic regression models to examine the relative contribution of racial/ethnic, biomedical, and socioeconomic factors to COVID-19 outcomes.

Methods

Study Region To aid in mitigating the potentially confounding association between race/ethnicity and socioeconomic status, we undertook our study in the San Francisco Bay Area where, not only is socioeconomic and racial diversity high, socioeconomic diversity is also evident within the racial/ethnic groups. The Bay Area population of 7.8 million residents (2020 U.S. Census) is majority non-White, with a racial/ethnic demographic composition consisting of 36% Whites, 6% Blacks, 28% Asians, 24% Hispanics, and 6% Other (2020 U.S. Census). This metropolitan region also exhibits marked income inequality, as evidenced by an 11-fold income difference between households in the 90th and the 10th income percentiles and the observation that fully one-third of the households are characterized as very low income [12, 13]. The Bay Area Asian population is particularly diverse, both ethnolinguistically as well as socioeconomically. According to the 2000 Census, 112 languages are spoken in the Bay Area, and more than half of the top 10 languages spoken in San Francisco are Asian languages [14]. As well, Bay Area Asian individuals are also particularly diverse, socioeconomically. As a group, Asian persons are evenly distributed across the income spectrum, with 31% of the group occupying the very low-income category and 36% in the high-income category [13, 15].

UCSF EHR Data Under an institutional review board (IRB)-approved protocol (IRB #20-30545), we analyzed the University of California, San Francisco (UCSF) COVID-19 Electronic Health Record (EHR) Data for Research. UCSF Health is a large, multi-hospital, multi-clinic academic medical health system with locations in five of the nine counties of the greater San Francisco Bay Area. The database includes the complete records of all UCSF Health patients who had undergone reverse transcriptase polymerase chain reaction (RT-PCR) testing, either as an outpatient or an inpatient, from January 1, 2020, to December 31, 2020, inclusive. Under an additional IRB-approved protocol, we geocoded each patient's address and attached U.S. Census Bureau data on demographics and socioeconomic characteristics corresponding to the smallest available census unit (i.e., census block or census tract) of the patient's residence. All other personally identifiable data were redacted to preserve the confidentiality of protected health information.

The complete data set was censored to include only records of patients who met all three of the following criteria: residency in one of the nine greater San Francisco Bay Area counties (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma); self-reporting of a single race or ethnicity; and completion of at least one SARS-CoV-2 RT-PCR test in calendar year 2020, during the pre-vaccination phase of the pandemic. To reduce referral bias effects that could have skewed the sample toward potentially sicker and more vulnerable patients, we eliminated from the sample all patients who resided outside the nine-county Bay Area, thereby reducing the sample size by approximately 15%. The time period was chosen to exclude the influence on clinical outcomes of vaccinations, none of which could have been completed until January 2021 for the earliest vaccinated individuals, a subset that constituted < 1% of the total study population. Since RT-PCR testing was not widely available during the first several months of 2020, relatively few tests were recorded in January 2020 and February 2020, but the number of tests increased steadily thereafter, starting in March 2020. The earliest test in the data set was performed on January 4, 2020, and the latest test result was performed on December 31, 2020.

Race/ethnicity was self-reported and classified as non-Hispanic Black (hereafter, Black), non-Hispanic White (hereafter, White), non-Hispanic Asian (hereafter Asian), or Hispanic or Latino (hereafter Hispanic). Because the small number of observations would preclude adequate statistical analysis of the Native Hawaiian or Other Pacific Islander group (< 1%), these patients were aggregated with the Asian group. For similar reasons, we did not conduct a separate analysis for American Indian or Alaska Native patients (< 1%) or for patients self-reporting as multi-racial (2.6%). A number of individuals did not self-report a race or ethnicity (8.4%). These patients, like the American Indian or Alaska Native and multi-racial patients, were included in the analyses of all patients but were excluded from the race-specific analyses. The racial and ethnic composition of the study cohort and that of the Bay Area population as a whole is shown in Table 1.

Outcome measures included COVID-19 test (SARS-CoV-2 RT-PCR) positivity and COVID-19-related hospitalization. Hospitalization for COVID-19 was defined by a non-procedural hospitalization for more than 24 h with an admitting diagnosis of COVID-19. For hospitalized patients, each record was examined for the presence of a set of biomedical factors/co-morbidities that have been reported in one or more previous studies to be associated with COVID-19 morbidity or mortality [16–21]. Conditions were defined by either the recording of a corroborative active ICD-9 or

Table 1 Racial/ethnic distribution of the study population in comparison to the San Francisco Bay Area

	White	Black	Hispanic	Asian
San Francisco Bay Area population	35.9%	5.6%	24.4%	28.3%
Study Population	57.9%	7.4%	19.0%	15.4%

ICD-10 diagnostic code in the EHR and/or by a laboratory value during the hospitalization that was consistent with the diagnosis. The conditions identified and the manner in which they were identified are as follows:

- Diabetes mellitus was defined by ICD-10 diagnosis of Type I diabetes mellitus (E10) or Type II diabetes mellitus (E11); by ICD-9 codes 249 or 250; and/or by any of the following abnormal laboratory values: blood hemoglobin A1C > 6.4%, serum glucose (either random or after an oral glucose tolerance test) > 200 mg/dL, or fasting serum glucose > 125 mg/dL. A subgroup of those with poorer glycemic control was defined by having a hemoglobin A1C > 7.5%;
- Kidney disease was defined by an ICD-10 code indicating chronic kidney disease (N18) and/or dialysis status (Z99.2); by ICD-9 codes 585.1, 585.2, 585.3, 585.4, 585.5, 585.6, and/or 585.9; and/or by a serum creatinine level that was above the normal range for the patient's age and gender (e.g., for adults < 60 years, serum creatinine ≥ 1.3 mg/dL in male patients and ≥ 1.1 mg/dL in female patients);
- Hypertension was denoted by ICD-10 diagnoses I10, R03.0, I16.0, I11, I15, I12, I50.2, and/or I50.4; ICD-9 code 401; and/or by at least two diastolic blood pressure measurements recorded on two separate days during hospitalization that exceeded 100 mm Hg;
- Dyslipidemia was defined by ICD-10 diagnostic code E78.5, ICD-9 code 272, and/or serum cholesterol ≥ 240 mg/dL;
- Obesity was defined by ICD-10 code E66, ICD-9 code 278, Body Mass Index (BMI) > 30 kg/m^2, and/or weight > 300 lbs. Severe obesity was defined by ICD-10 codes E66.01, E66.02, and/or Z68.4; ICD-9 code 278.01, BMI > 35 kg/m^2, and/or weight > 400. When BMI measurements were not available in the patient record, BMI was calculated from the latest available height and weight measurements recorded in the EHR on the date of hospitalization.
- Chronic Obstructive Pulmonary Disease (COPD) was defined by ICD-10 codes J42, J43, and/or J44; or ICD-9 codes 491.21, 491.22, 493.21, 493.22, 491.9, 492.8, and/or 492.0;
- Asthma was defined by ICD-10 code J45 or ICD-9 code 493;
- Cardiac disease was identified by ICD-10 codes I20-I25, I40, I48, I49, and/or I50; or ICD-9 codes 410, 411, 413, 414, 422, 428, 427, 429, and/or 440;
- Liver disease was defined by any of the ICD-10 codes between K70-K77, inclusive; or by ICD-9 codes 571, 572, and/or 573;
- Coagulation disorder was recorded for any ICD-10 code between D66-D69, inclusive, or for ICD-9 code 286;
- Cerebrovascular disorder was identified by ICD-10 codes G45, G46, H34.0, I6x, I97.81, and/or I97.82; or by ICD-9 codes 437 and/or 438;
- Cancer was defined by any of the ICD-10 codes between C01–Cxx, inclusive, in which "xx" denotes any two-digit number; or by ICD-9 codes 140–199, inclusive; and
- Smoking status, past or present, was designated by ICD-10 diagnoses F17, U07.0, T65.2, V15.82, Z71.6, Z72.0, or Z87.891; ICD-9 code 305.1 or V15.82; and/or by current smoking status or a past smoking history as recorded in the Social History section of the EHR.

Note that in order to remove any confounding effects from conditions that may have developed due to complications of COVID-19, only those conditions that were diagnosed prior to hospitalization were included. The exceptions were diabetes and hypertension, both of which are associated with relatively high rates of under-diagnosis. So as not to exclude newly diagnosed cases of either condition, we allowed these diagnoses to be established within three days of hospitalization.

Statistical Models We examined both individual-specific demographic factors (age, gender, and recorded medical insurance carrier) as well as context-specific factors (average household size and the Centers for Disease Control Social Vulnerability Index [CDC SVI]). The CDC SVI is a validated index that incorporates four different sub-measures: socioeconomic factors, household composition and disability status, minority status and primary language spoken, and housing type and primary transportation modality employed [22]. Health insurance status was denoted as "Medicaid" if at least one of the payors was Medicaid, MediCal (the California state Medicaid program), or the equivalent; or if the listed payor was listed as "charity care," "no insurance carrier," or the equivalent. Health insurance status was labeled as "private insurance" if at least one listed payor was a commercial insurance carrier. We did not include an indication of Medicare coverage as one of our insurance coverage variables since Medicare coverage in the United States is based on age and not income. Inclusion of such a group therefore would not have provided any additional information beyond the subanalysis of older individuals that we did perform.

Two sets of logistic regression analyses were performed. In the first set of analyses, all patients who underwent COVID-19 testing were included, and the dependent variable was COVID-19 test positivity. In the second set, the data were restricted to those patients who tested positive for COVID-19, and the dependent variable indicates whether the patient was hospitalized for COVID-19. For

each set of logistic regression analyses (positivity and hospitalization), five separate models were analyzed: one including all patients, and four others restricted to patients from only one of the four racial/ethnic groups (Black, White, Asian, and Hispanic). The model that includes all patients includes patients for whom race/ethnicity was not reported, reported as multi-racial, or as American Indian or Native American while the race-specific regressions include only patients from one race. For the independent variables in the test positivity analysis, we present results for a model in which only sociodemographic variables were included (Table 3 in the Appendix). We also present results for a subsequent analysis in which both individual-specific biomedical/health factors and contextual sociodemographic variables were included (Table 5 in the Appendix). For the hospitalization analysis, both health conditions and sociodemographic aspects were included as independent variables (Table 4 in the Appendix). The tables display the full regression results with all adjusted odds ratios (ORs) and their associated 95% confidence intervals. Statistical significance at the 0.05-level is indicated with an asterisk.

Results

COVID-19 Positivity Differences in the raw COVID-19 positivity rates were observed between the different racial/ethnic groups. In particular, rates of COVID-19 positivity were highest for Hispanic patients (11.8%), followed in descending order by Black patients (5.4%), Asian patients (3.7%), and White patients (2.5%). The difference between Hispanic and White patients was more than 4.5-fold. Figure 1 shows the adjusted odds ratios with their associated 95% confidence intervals for only the variables that were statistically significant at the 0.05-level in the logistic regression analysis for test positivity.

The higher test positivity rate for the Hispanic group and the lower test positivity rates for the Asian and White populations remained statistically significant even after controlling for age, gender, medical insurance coverage, average household size, and CDC Social Vulnerability Index. Thus, in our study population, for all groups except the Black population, the association of race/ethnicity and COVID-19 test positivity was statistically significant even after controlling for other demographic or socioeconomic variables.

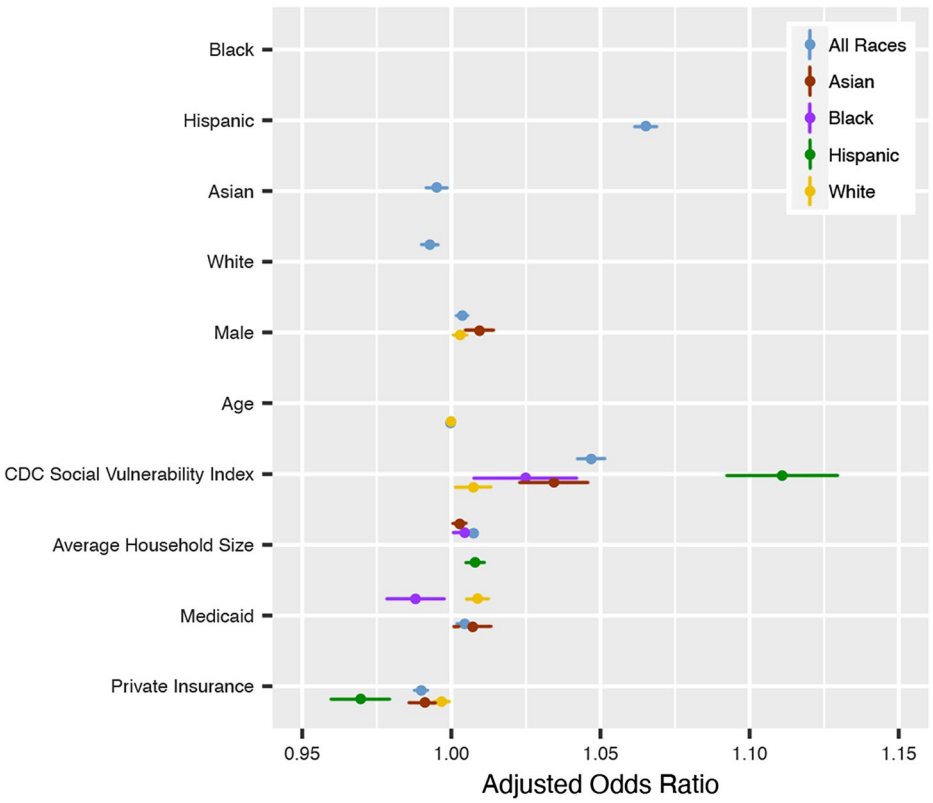

Fig. 1 COVID-19 positivity risk factors

Medicaid patients tended to test positive at higher rates, whereas those with private insurance tended to test positive at lower rates. A small positive relationship was noted between living in an area with larger average household sizes and the likelihood of testing positive for COVID-19. The middle 50 percent of the average household sizes were between 2.0 and 2.94 individuals, with the upper quartertile ranging between 2.94 and 7, and the lowest quartile below 2. The relationship of insurance coverage and average household sizes with positivity, while statistically significant, was relatively small in magnitude.

A substantially larger relationship was observed between residence in areas of higher social vulnerability and COVID-19 test positivity. The CDC SVI is a continuous variable with values in the range [0,1]. The CDC SVI distribution as described in summary statistics (Minimum, 1st Quartile, Mean, 3rd Quartile, Maximum) was (0.0, 0.216, 0.453, 0.677, 0.997) for the COVID-19 positive group and (0.0, 0.119, 0.326, 0.486, 0.997) for the COVID-19 negative group, indicating that individuals in the COVID-19 positive group were more likely to reside in areas associated with higher social vulnerability. The relationship between social vulnerability and test positivity was particularly large for Hispanic individuals. The odds of a positive test were 11% higher among Hispanic individuals who resided in the most socially vulnerable census tracts versus Hispanic persons who resided in the least vulnerable census tracts. While this relationship between higher social vulnerability and higher likelihood of testing positive was observed for all four racial/ethnic groups, the risk was highest for those whose ethnicity was Hispanic.

It is possible that people who resided in poorer living conditions may have been more susceptible to testing positive for COVID-19 because they were in generally poorer health. To explore this hypothesis, we performed a logistic regression model that included not just sociodemographic variables, but also biomedical risk factors (including diabetes, obesity, dyslipidemia, hypertension, cardiac disease, cerebrovascular disease, kidney disease, chronic obstructive pulmonary disease, asthma, smoking history, coagulopathy, and cancer). Interestingly, in this secondary analysis, while some health conditions reached the threshold of being statistically significant, the odds ratios were almost all less than 1.01 (i.e., 1% increased risk) and furthermore, most of the relationships were slightly negative (i.e., protective) rather than positive. Accordingly, on the whole, the examined biomedical factors had no clinically meaningful impact on the likelihood of testing positive for COVID-19. Aside from study-specific power limitations to detect such a relationship, it is possible that other factors, e.g., more medically

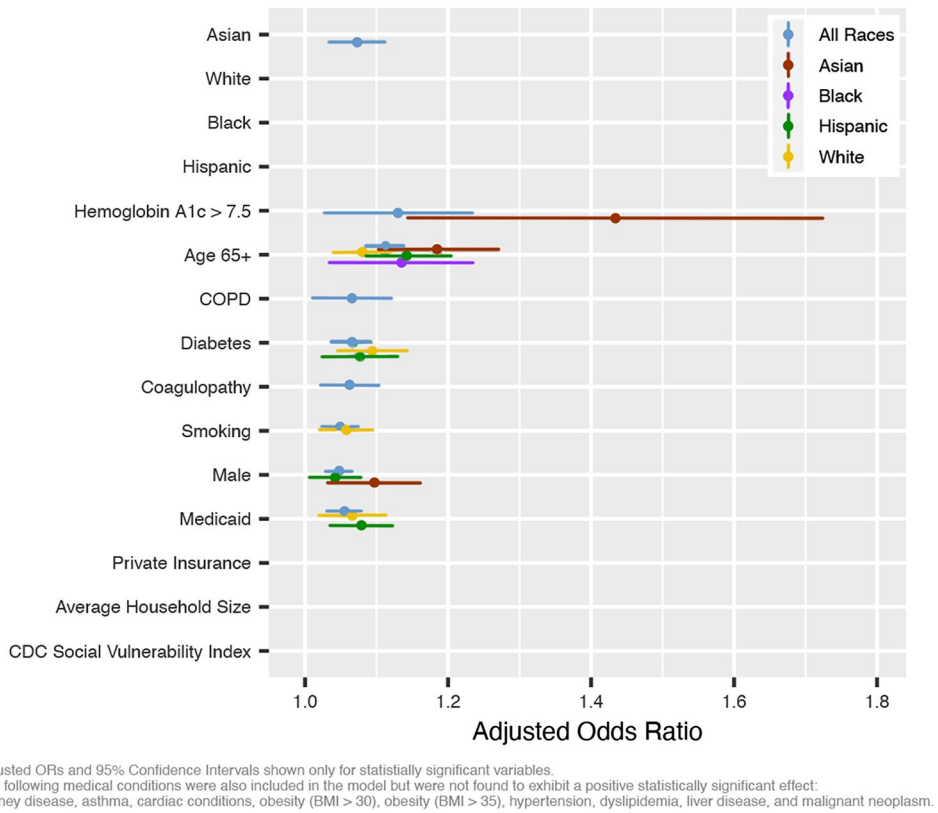

Fig. 2 COVID-19 hospitalization risk factors

vulnerable individuals practicing more stringent behavioral mitigation measures such as mask wearing and avoiding social gatherings, would offset such a finding. Regardless, whether biomedical conditions are considered or not, the results of both sets of regression models indicate that race/ethnicity and increased social vulnerability were statistically significant indicators of COVID-19 test positivity.

COVID-19 Hospitalization Of the 7280 individuals testing positive for COVID-19, 696 (6.5%) were hospitalized at UCSF Health. As noted previously [8], although Asian patients had the second-lowest rates of testing positive for COVID-19 among the four racial/ethnic groups, Asian patients also exhibited the highest rate of hospitalization. To investigate this observation further, a logistic regression was performed that included race/ethnicity, sociodemographic factors, and biomedical risk factors as independent variables, and COVID-19 hospitalization as the dependent variable. Inclusion criteria included all patients who tested positive for COVID-19. Five models were run: one including all individuals and one model each for the four studied racial/ethnic groups. Full regression results are presented in the Appendix (Table 4). Figure 2 shows the summary results in graphical form, displaying, in descending rank order, only those variables found to have a statistically significant relationship (at the 0.05-level) with the risk of hospitalization. Notably, Asian race conferred an increased and independent risk of COVID-19 hospitalization, even after controlling for biomedical and other sociodemographic factors. None of the other racial/ethnic groups was associated with either an increased or decreased risk of hospitalization.

Whereas the CDC Social Vulnerability Index (CDC SVI) was observed to be a statistically significant predictor of COVID-19 test positivity, neither the CDC SVI nor average household size had a statistically significant relationship with COVID-19 hospitalization. Only insurance status was found to have a statistically significant relationship, with Medicaid or no health insurance elevating the risk of hospitalization. Again, in contradistinction to the finding that biomedical factors had little to no relationship with COVID-19 test positivity, a number of health conditions were found to be independent and statistically significant predictors of COVID-19 hospitalization (Fig. 2). For the entire population, conditions that were associated with COVID-19 hospitalization included the following, in descending order of importance: higher severity diabetes with hemoglobin A1C > 7.5%, age ≥ 65 years, chronic obstructive pulmonary disease and diabetes (without respect to severity), coagulopathy, smoking, and male gender.

On an unadjusted basis, the presence of diabetes conferred a ~26% elevation in risk of COVID-19 positivity for Asian patients, whereas that risk was elevated by only ~ 12% when diabetes was present in White patients (Table 2). There was no appreciable increase in unadjusted COVID-19 positivity rates when diabetes was present in either Black or Hispanic patients.

Age and diabetes increased hospitalization risk to varying degrees, depending on a patient's race/ethnicity. Advanced age (65+ years) was a stronger risk factor for hospitalization among Asian patients than it was for individuals age 65 years and older from other racial/ethnic groups. Higher glycohemoglobin levels (> 7.5%), indicative of poorer glycemic control, were associated with a moderately increased hospitalization risk (adjusted odds ratio of 1.4), especially for Asian diabetics. For White diabetics, the adjusted odds ratio for higher glycohemoglobin levels (> 7.5%) was 1.3, with a *p*-value of 0.057 and a 95% confidence interval of (0.9933, 1.6797). Less severe diabetes was also a risk factor for hospitalization, though it conferred a more mild risk. The 7.7% increased risk of hospitalization for Hispanic diabetics and 9.4% increased risk for White diabetics were both significant at the 0.05-level, while an increased risk of 8.8% for Asian diabetics had a *p*-value of 0.051 and a 95% confidence interval of (0.9997, 1.1832). In our study population, diabetes was not associated with an increase in hospitalization risk for Black patients.

The proportion of hospitalized COVID-19 patients with diabetes that had no diagnosis of diabetes prior to hospitalization was 49% among Asian patients, compared to 46% among White patients, 39% among Black patients, and 35% in Hispanic patients. Moreover, upon first diagnosis in the hospital, Asian patients had the highest mean hemoglobin A1C (7.5%), compared to 7.3% in Hispanic diabetics and 6.5% in both White and Black diabetics, indicating that previously undiagnosed Asian diabetics had the poorest glycemic control in comparison to newly diagnosed Hispanic, Black, and White diabetics.

Table 2 Rates of COVID-positivity for Diabetic vs Non-Diabetic Patients, According to Race/Ethnicity

	White	Black	Hispanic	Asian
Diabetic	2.8%	5.6%	11.9%	4.4%
Non-diabetic	2.5%	5.5%	11.8%	3.5%

Divergence Between Correlates of COVID-19 Test Positivity and Hospitalization In the cohort studied, race/ethnicity (except in Black individuals) and poorer socioeconomic status (e.g., having Medicaid insurance or no health insurance or residing in a neighborhood with a higher average household size or an increased social vulnerability score) were generally associated with an increased risk of testing positive for COVID-19, whereas an individual's biomedical

profile played little to no role in increasing the likelihood of testing positive. The CDC Social Vulnerability Index is comprised of a number of different components that could have contributed to an increased risk for COVID-19 exposure and/or susceptibility to infection, including lack of English proficiency, transportation challenges, residence proximate to environmental pollutants, and increased household density. Further investigation to examine the impact of the various components of the CDC SVI would be needed to ascertain their relative contributions to COVID-19 transmission and/or susceptibility risk. Such a study would be helpful in designing targeted interventions and formulating policy aimed at improving population health and addressing social determinants of health inequities, particularly for vulnerable subpopulations.

By contrast, for COVID-19 hospitalization, nearly the opposite pattern emerged—almost all the statistically significant risk factors were in the biomedical domain. The greatest risk factors were higher severity diabetes mellitus and advanced age (65 years or older), but other risk factors included coagulopathy, diabetes mellitus (regardless of severity), severe obesity, male gender, smoking, and asthma. Asian race, irrespective of biomedical and other sociodemographic factors, was an independent risk factor for hospitalization; Asian patients who tested positive for COVID-19 had more than twice the hospitalization rate of White patients who were COVID-19 positive. Of the other examined sociodemographic factors, only poorer health insurance status (i.e., Medicaid or no health insurance) was associated with a small increased risk of hospitalization. The other sociodemographic factors, including those in the CDC Social Vulnerability Index, were not statistically significant predictors of hospitalization risk.

Impact of Race/Ethnicity Although Black individuals tested positive at rates that were more than double that of White individuals and were hospitalized at rates second only to Asian individuals, no additional relationship with Black race was noted once sociodemographic and biomedical variables were taken into account. In other words, the excess risk attributable to being Black could be explained by other sociodemographic factors and biomedical predispositions. If these findings are corroborated, then efforts to alleviate COVID-19 health disparities for the Black population might best be directed toward addressing contributors to socially vulnerability and improving the health status of Black persons.

Hispanic ethnicity was an independent correlate of increased rates of COVID-19 positivity, irrespective of other sociodemographic factors, but it was not a significant correlate of COVID-19 hospitalization risk. Furthermore, while increased social vulnerability was associated with a higher rate of COVID-19 positivity for all racial/ethnic groups, the magnitude of this relationship was the highest for Hispanic patients. Although the reason(s) for this difference are unclear and warrant additional study, one potentially promising line of inquiry would be to consider whether this elevated rate is related to the younger-skewing age distribution of Hispanic individuals in the United States. A report by the Pew Research Center found that in 2014, close to 60% of all U.S. Hispanic persons were Millennials (ages 18 to 33 years) or younger. By comparison, half of the U.S. Black population, 46% of the U.S. Asian population, and 39% of U.S. White persons were of Millennial age or younger [23]. In our study population, the average age of the Hispanic population was 33.7 years, considerably younger than the White, Black, and Asian groups, whose average ages were 52.2, 43.4, and 46.2 years, respectively. It is possible that younger Hispanic individuals are disproportionately represented in frontline ("essential worker") jobs, in which the risk of COVID-19 transmission would be expected to be higher than for occupations allowing remote work from home. If these findings are validated, a focus on prevention in at-risk Hispanic subpopulations, including vaccination and behavioral, non-pharmaceutical interventions such as masking and social distancing could be helpful. It is also worth considering how the tasks and work environment of these essential worker jobs might be adjusted to mitigate coronavirus transmission and how health education, sick leave policy, and availability of affordable health care for essential workers might promote behaviors that reduce the risk of disease transmission in the workplace.

In our study, Asian individuals were distinct among the four racial/ethnic groups in exhibiting a higher risk for COVID-19 hospitalization, even after adjusting for age, medical co-morbidities, and other sociodemographic characteristics. Based on logistic regression analysis, none of the other racial/ethnic identities was independently correlated with COVID-19 hospitalization risk. Further inquiry is warranted to understand the excess risk posed by Asian identity since many of the data measures incorporated in our study were not able to fully capture the range of potential barriers to health care that may confront many individuals within the highly diverse Asian cohort. Since immigrants form a markedly higher percentage of the U.S. adult Asian population (71%) compared to the general U.S. adult population (17%) [24], many individuals within the Asian cohort may face additional challenges in accessing health care [25–27]. Health care access and health care utilization in Asian individuals may be hindered, for instance, by language barriers, limited digital access, unavailability of ethnolinguistically concordant health care providers, preferences for non-Western

traditional treatment approaches, and/or cultural differences in health care beliefs, behaviors, and practices [25, 28–31]. Moreover, because Asian immigration to the U.S. has historically been influenced by labor demands, many Asian immigrants, including older Asian adults, are in essential worker occupations that may pose a higher risk of COVID-19 exposure. One in five Asian adults aged 55 years and older work in frontline service jobs, compared to only 15% of the total U.S. population [32], which may partly explain why older Asian adults experience a higher rate of hospitalization for COVID-19, even after controlling for other biomedical and sociodemographic factors.

Impact of Diabetes Mellitus The impact of diabetes on COVID-19 positivity and COVID-19 hospitalization risk in Asian patients is noteworthy, especially since the proportion of diabetics with previously undiagnosed diabetes was higher for Asian patients than for any other race/ethnicity, and the average hemoglobin A1C levels during hospitalization was again highest for Asian diabetics. A strong link between diabetes mellitus and COVID-19 hospitalization was reported in a 2020 Israeli study in which the only risk factor associated with an increased risk of COVID-19 hospitalization was severe diabetes with A1C > 9% [33]. In Asians, diabetes occurs more frequently in non-obese individuals [34] and at lower BMI [35]. A proposed explanation for these differences includes higher visceral adiposity for a given BMI in Asian individuals versus non-Asian individuals. Similar to what we observed, Menke et al. [36] found that more than half of Asian persons with diabetes were undiagnosed. Other investigators have reported that diabetes is more frequently underdiagnosed in Asian and Hispanic individuals compared to White and Black persons [37]. Further study is needed to understand the pathophysiologic mechanism(s) by which diabetes contributes to excess morbidity risk in COVID-19. Efforts to mitigate excess risk of COVID-19 morbidity for Asian persons might focus on diagnosis and treatment of diabetes but must also consider factors that are specific to the Asian population (e.g., language concordance, dietary and lifestyle habits, health beliefs, health literacy, traditional health care usage, and other culture-specific health-related behaviors that may affect willingness to seek health care, ability to access health care services, and compliance with recommended management).

Discussion

Our study highlights the complex interplay of individual-specific and contextual factors on racial and ethnic health disparities in COVID-19 test positivity and hospitalization in the San Francisco Bay Area. We observed considerable intergroup variation in the factors that were associated with such disparities as well as the differential impact of COVID-19 across racial/ethnic groups.

We extend some studies that were conducted on similar populations. McCloskey and colleagues [38] examined a Medicaid and Medicare subset of insured patients from Northern California and Colorado and, similar to our findings, observed higher rates of COVID-19 positivity in non-White racial/ethnic groups, independent of biomedical and social vulnerability factors. However, their study cohort was limited to including only lower-income, Medicaid-insured individuals and older-age (i.e., generally 65 years and over), Medicare-insured individuals. Furthermore, their study was limited to an examination of test positivity and did not examine risk factors for hospitalization. In another report, Escobar et al. [39] examined a cohort of insured patients in a large San Francisco Bay Area integrated health care system during a 4-month period at the start of the pandemic and, similar to what we now report, discovered increased test positivity rates in non-White patients. However, in contrast to what we found, those researchers described minimal contributions of race/ethnicity to COVID-19 hospitalization rates and furthermore observed no significant racial/ethnic intergroup differences in the prevalence of diabetes among patients hospitalized with COVID-19. Our study cohort differed in meaningful ways by examining cases over a 12-month period in the pre-vaccination phase of the pandemic (versus 4 months in early 2020), including the latter half of 2020 when COVID-19 testing became more widely available, detection rates of milder and asymptomatic cases increased, and admission criteria for hospitalization evolved. Furthermore, our cohort included uninsured patients, which may then result in a higher proportion of more socially vulnerable patients.

Implications and Directions for Future Studies Further research is needed to corroborate our findings in other populations; to delineate the pathophysiologic basis for the apparent increased morbidity conferred by certain biomedical co-morbidities including diabetes mellitus; and to elucidate the as-yet unexplained basis for the excess rates of test positivity associated with non-White race/ethnicity and the higher incidence of hospitalization associated with Asian race, even after adjusting for a number of biomedical and sociodemographic risk factors.

An improved understanding of mechanisms underlying racial/ethnic health disparities would shed insights into the relative contributions of factors that might be broadly classified into two inherently intersectional domains: *individual-specific* factors that affect a person's susceptibility to and manifestation of disease,

which may reflect allelic, epigenetic, and behavioral variations that are influenced by an individual's race/ethnicity, age, gender, health status, genetic background, ancestry, culture, beliefs, and health-related practices and *contextual, group-specific* factors that reflect multiplex systemic, historical, legal, economic, social, interpersonal, and structural racism-related impacts on minority and vulnerable populations, including with respect to their attributes of health, access to health care, and experience of health care delivery.

Neither of these domains alone may explain all of the observed differences in health measures based on race and ethnicity. On the one hand, the phenotypic expression of disease is dependent not just on intrinsic genomic determinants but also by multiple epigenetic and environmental externalities, including age, gender, co-morbidities, diet, substance use, exposures, and health-related behaviors, all of which are intimately tied to an individual's life experiences and social context. At the same time, an individual's environment and experience of racism may have differential effects on health depending on that person's age, gender, medical status, genetics, and other biomedical predispositions as well as individual-specific health-related behaviors and beliefs. Ideally, a comprehensive analysis of racial and ethnic health disparities should include the broadest possible consideration of a spectrum of factors across biomedical, behavioral, social, cultural, demographic, and other contextual domains.

A particular challenge for studies of health equity is not just to understand and measure the health care consequences of racial/ethnic identity but also to elucidate, identify, and quantify the contextual effects of racism on health and health care for individuals and populations. Certainly, the consequences of slavery, Jim Crow laws, oppressive policing policies, inequitable housing conditions, and discriminatory immigration and refugee policies may continue to perpetuate mutually reinforcing, systemically rooted societal inequalities in education, employment, advancement opportunities, and income/wealth. Moreover, the consequences of these policies may reinforce stereotyped treatment and resource maldistribution that subsequently translate into poorer mental and physical wellness and reduced access to health care. Although challenging to characterize, measure, and mitigate, systemic racism is likely an important contributor to ongoing racial and ethnic health disparities and remains a vital priority for future scientific scholarship and health policy research.

Conceptually and practically, it is imperative to gain a broader understanding of how race/ethnicity and racism can influence or intersect with an individual's biomedical makeup, behavior, and social context by directly and/or indirectly influencing health, health care, predisposition to illness, and the incidence, transmission, manifestation, treatment and prevention of disease. Race/ethnicity can influence health through ancestry-related genetic/allelic variations as well as health-related behaviors influenced by a person's race/ethnicity, cultural identity, and upbringing (e.g., diet, habits, household composition, health beliefs, health literacy, health practices, etc.). Accordingly, measures targeted at improving health, promoting health-conscious behaviors, and delivering culturally sensitive and contextually appropriate health care (including provisions for race-concordant and language-concordant care) are instrumental for devising comprehensive and effective approaches to closing health equity gaps. This nuanced but critical distinction is important, not only for understanding the underlying causes of health disparities, but also for appropriately crafting policy, wisely allocating resources, and effectively implementing measures to holistically address racial and ethnic health inequities.

Study Limitations Our study was conducted on the patient population of a large academic health care system in the San Francisco Bay Area during the pre-vaccination phase of the COVID-19 pandemic; accordingly, these specific findings may not be generalizable to populations in other settings or at different time points. Furthermore, there were differences between the racial and ethnic composition of the study cohort and that of the Bay Area. The proportions of White persons and Black individuals was higher in the study group than in the Bay Area population as a whole; conversely, the percentage of Asian individuals in the study cohort was lower. These differences possibly reflect differences in the demographics of the counties closest to UCSF Health locations, variations in patient access to and willingness to seek care at UCSF Health care facilities, health insurance coverage-dictated limitations, and referral effects. Patients who lived a distance from a UCSF Health facility, and particularly individuals with higher social vulnerability and lower socioeconomic status, may have been less likely to seek care at UCSF Health and thus would been less likely to be included in the study population. Mitigating any such effects is the fact that, among the largest regional health care systems in the San Francisco Bay Area during the study period, UCSF Health cared for a large share of uninsured and underinsured patients [40].

A modest proportion of otherwise eligible patients were excluded from analysis because self-reported race/ethnicity was either omitted (8.4%) or indicated as multiracial (2.6%). However, examination of COVID-19 test

positivity rates suggests that the composition of these excluded individuals was likely comparable to that of the groups included in the study. The COVID-19 test positivity rates were 2.5% for White individuals, 5.4% for Black persons, 3.7% for Asian individuals, and 11.8% for Hispanic persons. The weighted average test positivity rate for these four groups combined was 4.7%, similar to the 4.4% test positivity rate for the group with missing race/ethnicity information, and the 3.7% positivity for the multi-racial group (2.6% of the total population). Accordingly, missingness of data with respect to race and ethnicity is unlikely to have had a large impact on the overall findings of the study.

Errors in self-reported residence address data were corrected manually when possible (e.g., misspelled street names and transposed zip code digits) but records with missing street addresses or other unresolvable errors were excluded. These limitations may have introduced some systematic errors, such as underreporting of homeless individuals, but the magnitude of such errors is unknown.

It was not possible to capture data from any individuals who may have moved out of the area or migrated to another health care system between the time of COVID-19 testing and hospitalization, so it is possible that the number of hospitalizations may have been underreported. However, there have been no published studies that would suggest that during the COVID-19 pandemic, any such effect would have been more likely to affect one racial and ethnic group over another or to preferentially affect individuals of higher or lower social vulnerability. Thus, even if a mild degree of undercounting had been present, the effects are unlikely to have been large or to have substantially altered the study findings.

Conclusion

We observed that biomedical, racial/ethnic, and sociodemographic factors all contributed in varying but distinct ways to COVID-19 test positivity and hospitalization rates in a multi-racial, socioeconomically diverse U.S. metropolitan area. Hispanic ethnicity and increased social vulnerability correlated strongly with a higher likelihood of COVID-19 test positivity. Asian race, age, higher severity diabetes, older age, male gender, coagulopathy, smoking, and Medicaid/uninsured status all correlated with a higher likelihood of COVID-19-related hospitalization. Diabetes emerged as an important contributor to COVID-19 morbidity, particularly for Asian patients, who had the highest frequency of previously undiagnosed diabetes and the worst glycemic status.

Sociodemographic and group contextual factors generally appeared most important for influencing the risk of acquiring COVID-19 infection, whereas biomedical and individual-specific factors contributed to a higher likelihood of developing COVID-19-associated morbidity (i.e., hospitalization). Even so, there remained race/ethnicity-associated elevated risks (e.g., elevated test positivity rates for Hispanic individuals and increased hospitalization rates for Asian persons) that were not explained by the variables examined in this study. We have proffered a number of potential explanations for these race/ethnicity effects but further inquiry would be needed to elucidate the underlying causes and potentially guide appropriate mitigations for these effects.

We suggest that evaluating and addressing causes of racial and ethnic health disparities require acknowledging a spectrum of factors that can influence health outcomes, which can be broadly classified into intersectional domains of *individual-specific* and *group contextual* factors. The former would include not only biomedical and genetic predispositions, but also epigenetic, behavioral, and other exogenous factors that operate at the individual level. The latter would include socioeconomic and demographic factors, including those that primarily affect a particular racial or ethnic group, suggesting possible underlying systemic or structural contributors to health disparities.

Improving COVID-19 outcomes in the population overall and addressing racial and ethnic health disparities in particular will likely require a comprehensive, data-driven approach that includes not only diagnostic, vaccination-based, pharmacotherapeutic, and non-pharmaceutical interventions, but also strategies to target both individual-specific and group contextual factors that contribute to increased transmission, susceptibility, and severity of SARS-CoV-2-related disease. Finally, our findings emphasize that population health is strongly dependent on protecting the most vulnerable among us. Socially vulnerability affects infection, while those with co-morbidities, whether socially vulnerable or not, were at risk for hospitalization. Mitigating the factors that create increased infection among the socially vulnerable protects not just the socially vulnerable, but us all.

Appendix

Table 3 Odds ratios with 95% confidence intervals for logistic regression models of COVID-19 positivity

	All Races		Black		White		Asian		Hispanic	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Intercept	1.0205*	(1.0154, 1.0254)	1.0461*	(1.0278, 1.0647)	1.038*	(1.0316, 1.0438)	1.019*	(1.0092, 1.0292)	1.060*	(1.0411, 1.0785)
Age	0.9998*	(0.9998, 0.9998)	0.9998	(0.9996, 1.0000)	1.000*	(1.0000, 1.0000)	1.000	(1.0000, 1.0000)	1.000	(1.0000, 1.0000)
Male	1.0037*	(1.0015, 1.0058)	1.0022	(0.9934, 1.0110)	1.003*	(1.0010, 1.0049)	1.009*	(1.0031, 1.0149)	1.003	(0.9951, 1.0108)
Asian	0.9952*	(0.9917, 0.9987)								
Black	0.9993	(0.9944, 1.0042)								
White	0.9927*	(0.9898, 0.9956)								
Hispanic	1.0652*	(1.0611, 1.0691)								
Medicaid	1.0044*	(1.0014, 1.0073)	0.9880*	(0.9785, 0.9975)	1.0090*	(1.0050, 1.0130)	1.0070*	(1.0011, 1.0129)	0.9930	(0.9833, 1.0028)
Private Insurance	0.9898*	(0.9875, 0.9921)	0.9989	(0.9891, 1.0087)	0.9970*	(0.9950, 0.9989)	0.9910*	(0.9852, 0.9968)	0.9700*	(0.9600, 0.9790)
Average Household Size	1.0074*	(1.0059, 1.0087)	1.0044*	(1.0004, 1.0083)	0.9990	(0.9970, 1.0009)	1.0030*	(1.0010, 1.0049)	1.0080*	(1.0040, 1.0119)
CDC Social Vulnerability Index	1.0470*	(1.0420, 1.0519)	1.0249*	(1.0073, 1.0427)	1.0070*	(1.0011, 1.0129)	1.0340*	(1.0224, 1.0468)	1.1110*	(1.0912, 1.1304)
Total Number of Patients Testing	133,390		10,550		72,774		23,880		22,744	

*$p < 0.05$

Table 4 Odds ratios with 95% confidence intervals for logistic regression models of COVID-19 hospitalization

	All Races		Black		White		Asian		Hispanic	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Intercept	1.021	(0.9704, 1.0746)	1.022	(0.8738, 1.1957)	1.071	(0.9954, 1.1508)	1.036	(0.9081, 1.1809)	1.027	(0.9480, 1.1133)
Age 65+	1.112*	(1.0817, 1.1427)	1.135*	(1.0314, 1.2498)	1.080*	(1.0385, 1.1232)	1.185*	(1.0916, 1.2870)	1.142*	(1.0749, 1.2138)
Male	1.048*	(1.0277, 1.0688)	1.075†	(0.9994, 1.1554)	1.021	(0.9887, 1.0527)	1.097*	(1.0287, 1.1707)	1.042*	(1.0057, 1.0792)
Asian	1.073*	(1.0312, 1.1153)								
Black	1.012	(0.9693, 1.0566)								
White	1.001	(0.9663, 1.0369)								
Hispanic	1.034†	(0.9996, 1.0685)								
Diabetes mellitus	1.066*	(1.0352, 1.0979)	1.037	(0.9435, 1.1389)	1.094*	(1.0438, 1.1468)	1.088†	(0.9997, 1.1832)	1.077*	(1.0213, 1.1353)
Hemoglobin A1C > 7.5	1.130*	(1.0222, 1.2485)	0.968	(0.7791, 1.2038)	1.292†	(0.9933, 1.6797)	1.434*	(1.1120, 1.756)	1.061	(0.9015, 1.2481)
Chronic Obstructive Pulmonary Disease	1.066*	(1.0091, 1.1262)	1.083	(0.9370, 1.2523)	1.042	(0.9680, 1.1235)	0.988	(0.8529, 1.1445)	1.109	(0.9504, 1.2954)
Kidney Disease	0.990	(0.9613, 1.0195)	1.051	(0.9587, 1.1527)	1.010	(0.9636, 1.0586)	0.962	(0.8788, 1.0524)	0.959	(0.9058, 1.0149)
Asthma	1.027	(0.9995, 1.0559)	1.040	(0.9529, 1.1367)	1.017	(0.9742, 1.0619)	1.032	(0.9453, 1.1277)	1.022	(0.9714, 1.0756)
Heart Disease	1.003	(0.9739, 1.0329)	1.016	(0.9212, 1.1207)	0.988	(0.9463, 1.0316)	1.004	(0.9192, 1.0965)	1.012	(0.9561, 1.0712)
Obesity (BMI > 30)	1.011	(0.9856, 1.0371)	1.005	(0.9147, 1.1041)	1.026	(0.9849, 1.0694)	0.946	(0.8725, 1.0246)	1.008	(0.9635, 1.0545)
Obesity (BMI > 35)	0.997	(0.9681, 1.0267)	0.962	(0.8771, 1.0545)	0.989	(0.9417, 1.0387)	1.098	(0.9872, 1.2199)	1.012	(0.9655, 1.0608)
Smoking	1.049*	(1.0227, 1.0762)	1.009	(0.9220, 1.1042)	1.058*	(1.0189, 1.0977)	1.076	(0.9926, 1.1657)	1.026	(0.9762, 1.0768)
Hypertension	0.992	(0.9651, 1.0196)	0.908*	(0.8268, 0.9980)	1.010	(0.9693, 1.0524)	0.989	(0.9109, 1.0739)	0.989	(0.9399, 1.0407)
Dyslipidemia	0.971*	(0.9441, 0.9974)	1.002	(0.9120, 1.1008)	0.974	(0.9341, 1.0142)	0.990	(0.9136, 1.0728)	0.952	(0.9013, 1.0058)
Liver Disease	1.017	(0.9818, 1.0536)	1.074	(0.9304, 1.2387)	1.091*	(1.0286, 1.1569)	0.978	(0.8834, 1.0832)	0.986	(0.9297, 1.0458)
Coagulopathy	1.062*	(1.0190, 1.1064)	1.131	(0.9897, 1.2921)	0.995	(0.9363, 1.0573)	1.097	(0.9586, 1.2563)	1.075†	(0.9975, 1.1577)
Cancer	0.999	(0.9475, 1.0532)	0.887	(0.6955, 1.1309)	0.983	(0.9197, 1.0508)	1.044	(0.8889, 1.2259)	1.002	(0.8978, 1.1182)
Medicaid	1.055*	(1.0289, 1.0827)	1.020	(0.9414, 1.1055)	1.066*	(1.0171, 1.1174)	1.017	(0.9404, 1.1000)	1.079*	(1.0334, 1.1265)
Private Insurance	0.964*	(0.9403, 0.9895)	0.956	(0.8821, 1.0359)	0.958	(0.9138, 1.0040)	0.961	(0.8848, 1.0432)	0.995	(0.9530, 1.0388)
Average Household Size	1.002	(0.9902, 1.0138)	1.010	(0.9712, 1.0504)	0.987	(0.9679, 1.0066)	1.017	(0.9838, 1.0516)	1.006	(0.9845, 1.0279)
CDC Social Vulnerability Index	0.983	(0.9407, 1.0254)	1.049	(0.8977, 1.2236)	0.965	(0.8963, 1.0402)	0.968	(0.8426, 1.1131)	0.975	(0.9017, 1.0548)
Total Number of Patients Testing Positive	7,280		564		1868		883		2696	

* $p < 0.05$

† $p < 0.06$

Table 5 Odds ratios with 95% confidence intervals for biomedical logistic regression models of COVID-19 positivity

	All Races		Black		White		Asian		Hispanic	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Intercept	1.013*	(1.0051, 1.0210)	1.022	(0.9984, 1.0465)	1.031*	(1.0234, 1.0396)	1.015*	(1.0012, 1.0291)	1.016	(0.9915, 1.0392)
Age 65+	0.994*	(0.9901, 0.9979)	0.998	(0.9844, 1.0117)	0.993*	(0.9891, 0.9969)	1.000	(0.9921, 1.0078)	0.978*	(0.9611, 0.9956)
Male	1.004*	(1.0020, 1.0059)	1.012*	(1.0002, 1.0240)	1.004*	(1.0000, 1.0079)	1.005	(0.9991, 1.0109)	1.001	(0.9892, 1.0128)
Asian	0.997	(0.9911, 1.0028)								
Black	1.000	(0.9941, 1.0058)								
White	0.994*	(0.9901, 0.9979)								
Hispanic	1.056*	(1.0492, 1.0617)								
Diabetes mellitus	1.008*	(1.0040, 1.0119)	1.009	(0.9952, 1.0229)	1.002	(0.9980, 1.0059)	1.013*	(1.0051, 1.0210)	1.018*	(1.0023, 1.0342)
Hemoglobin A1C > 7.5	1.009	(0.9913, 1.0269)	1.024	(0.9820, 1.0662)	0.996	(0.9709, 1.0217)	1.027	(0.9917, 1.0642)	1.018	(0.9609, 1.0766)
Chronic Obstructive Pulmonary Disease	0.994	(0.9881, 0.9998)	1.005	(0.9845, 1.0238)	0.999	(0.9911, 1.0068)	0.997	(0.9814, 1.0127)	0.962*	(0.9293, 0.9972)
Kidney Disease	0.999	(0.9950, 1.0029)	1.005	(0.9913, 1.0188)	0.998	(0.9940, 1.0019)	1.001	(0.9912, 1.0108)	1.001	(0.9834, 1.0188)
Asthma	1.003	(0.9990, 1.0069)	1.007	(0.9933, 1.0209)	1.007*	(1.0030, 1.0109)	1.011*	(1.0012, 1.0210)	0.990	(0.9746, 1.0056)
Heart Disease	0.998	(0.9940, 1.0019)	1.004	(0.9903, 1.0178)	1.000	(0.9960, 1.0039)	1.001	(0.9931, 1.0088)	0.989	(0.9736, 1.0046)
Obesity (BMI > 30)	1.009*	(1.0050, 1.0130)	1.014	(1.0002, 1.0281)	1.003	(0.9990, 1.0069)	1.011*	(1.0031, 1.0190)	1.024*	(1.0093, 1.0374)
Obesity (BMI > 35)	1.007*	(1.0030, 1.0109)	1.003	(0.9893, 1.0168)	1.002	(0.9961, 1.0079)	1.015*	(1.0032, 1.0271)	1.022*	(1.0063, 1.0383)
Smoking	0.995*	(0.9911, 0.9989)	0.978*	(0.9668, 0.9898)	0.998	(0.9940, 1.0019)	1.004	(0.9961, 1.0119)	0.993	(0.9785, 1.0057)
Hypertension	1.000	(0.9960, 1.0039)	0.999	(0.9853, 1.0128)	1.000	(0.9960, 1.0039)	0.998	(0.9902, 1.0058)	1.007	(0.9913, 1.0229)
Dyslipidemia	0.999	(0.9950, 1.0029)	1.001	(0.9873, 1.0148)	1.000	(0.9960, 1.0039)	0.991*	(0.9833, 0.9988)	0.997	(0.9814, 1.0127)
Liver Disease	0.998	(0.9940, 1.0019)	0.982	(0.9649, 0.9996)	1.001	(0.9951, 1.0069)	1.001	(0.9912, 1.0108)	0.996	(0.9785, 1.0137)
Coagulopathy	0.995*	(0.9896, 0.9998)	1.001	(0.9815, 1.0208)	0.997	(0.9911, 1.0028)	0.980*	(0.9687, 0.9917)	0.993	(0.9718, 1.0146)
Cancer	0.995	(0.9891, 1.0008)	0.969*	(0.9450, 0.9944)	0.997	(0.9911, 1.0028)	0.993	(0.9794, 1.0067)	0.996	(0.9652, 1.0277)
Medicaid	1.010*	(1.0060, 1.0140)	0.988	(0.9746, 1.0017)	1.009*	(1.0031, 1.0149)	1.013*	(1.0051, 1.0210)	1.014*	(1.0002, 1.0281)
Private Insurance	0.994*	(0.9901, 0.9979)	1.002	(0.9883, 1.0158)	0.995	(0.9891, 1.0008)	0.996	(0.9862, 1.0058)	0.992	(0.9785, 1.0057)
Average Household Size	1.006*	(1.0040, 1.0079)	1.007*	(1.0011, 1.0129)	0.998	(0.9960, 0.9999)	1.003	(0.9990, 1.0069)	1.016*	(1.0101, 1.0221)
CDC Social Vulnerability Index	1.032*	(1.0254, 1.0375)	1.021	(0.9984, 1.0424)	1.008*	(1.0001, 1.0159)	1.020*	(1.0062, 1.0342)	1.067*	(1.0423, 1.0925)
Total Number of Patients Testing	133,390		10,550		72,774		23,880		22,744	

*$p < 0.05$

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Declarations

Ethics Approval This study was approved by the University of California San Francisco Human Research Protection Program Institutional Review Board (IRB #2030987. Reference #324788).

Conflict of Interest The authors declare no competing interests.

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