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Contribution of Individual- and Neighborhood-Level Social, Demographic, and Health Factors to COVID-19 Hospitalization Outcomes

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Background: Although disparities in COVID-19 outcomes have been observed, factors contributing to these differences are not well understood.

Objective: To determine whether COVID-19 hospitalization outcomes are related to neighborhood-level social vulnerability, independent of patient-level clinical factors.

Design: Pooled cross-sectional study of prospectively collected data.

Setting: 38 Michigan hospitals.

Patients: Adults older than 18 years hospitalized for COVID-19 in a participating site between March and December 2020.

Measurements: COVID-19 outcomes included acute organ dysfunction, organ failure, invasive mechanical ventilation, intensive care unit stay, death, and discharge disposition. Social vulnerability was measured by the social vulnerability index (SVI), a composite measure of social disadvantage.

Results: Compared with patients in low-vulnerability ZIP codes, those living in high-vulnerability ZIP codes were more frequently treated in the intensive care unit (29.0% vs. 24.5%); more frequently received mechanical ventilation (19.3% vs. 14.2%); and experienced higher rates of organ dysfunction (51.9% vs. 48.6%), organ failure (54.7% vs. 51.6%), and in-hospital death (19.4% vs. 16.7%). In mixed-effects regression analyses accounting for age, sex, and comorbid conditions, an increase in a patient's neighborhood SVI by 0.25 (1 quartile) was associated with greater likelihood of mechanical ventilation (increase of 2.1 percentage points), acute organ dysfunction (increase of 2.8 percentage points), and acute organ failure (increase of 2.8 percentage points) but was not associated with intensive care unit stay, mortality, or discharge disposition.

Limitation: Observational data focused on hospitalizations in a single state.

Conclusion: Hospitalized patients with COVID-19 from socially vulnerable neighborhoods presented with greater illness severity and required more intensive treatment, but once hospitalized they did not experience differences in hospital mortality or discharge disposition. Policies that target socially vulnerable neighborhoods and access to COVID-19 care may help ameliorate health disparities.

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Disparities in COVID-19 incidence and outcomes related to patient characteristics (such as race or ethnicity) and geographic areas (such as neighborhoods) are well known (1–4). For example, in a recent systematic review, Black and Hispanic populations were found to experience disproportionate burdens of COVID-19 infection, hospitalization, and overall mortality (4). We previously found that U.S. counties with higher levels of social vulnerability or disadvantage—based on socioeconomic status, housing, and other factors—experienced greater COVID-19 incidence and mortality (3). Although we know that where a person lives affects their health, the interplays between individual- and neighborhood-level social, demographic, and health factors to COVID-19 outcomes are complex and understudied for hospital-based outcomes (5). Understanding the contributions of these domains to health outcomes is important for public health and health care policy.

Previous studies that have sought to understand disparities in COVID-19 health outcomes have been limited to cross-sectional or cohort studies of patients at a single health care system (6) or to ecological studies analyzing population-level as opposed to patient-level data (4). Cohort studies from multiple health care systems are uncommon, and those that are published have not been able to disentangle the contributions of a patient's individual clinical factors from neighborhood contextual effects on COVID-19 outcomes. In addition, less is known about what factors influence disparities in COVID-19 outcomes, whether related to greater exposure to COVID-19 infection, greater susceptibility to infection after exposure, or differential access to care (4).

The social vulnerability index (SVI), developed by the Centers for Disease Control and Prevention, provides an aggregate measure of neighborhood social factors known to affect public health crises, including disease outbreaks (7). Because it has been used frequently by public health authorities to investigate populations at higher risk for COVID-19, SVI represents an ideal tool with which to examine how social factors may or may not contribute to COVID-19 outcomes (7–9). Therefore, we used data from a multihospital cohort and ZIP code–linked SVI to quantify

how individual- and neighborhood-level factors influenced outcomes after hospitalization for COVID-19. Our objective was to determine whether COVID-19 hospitalization outcomes were related to neighborhood-level social vulnerability or disadvantage, independent of patient-level clinical factors.

METHODS

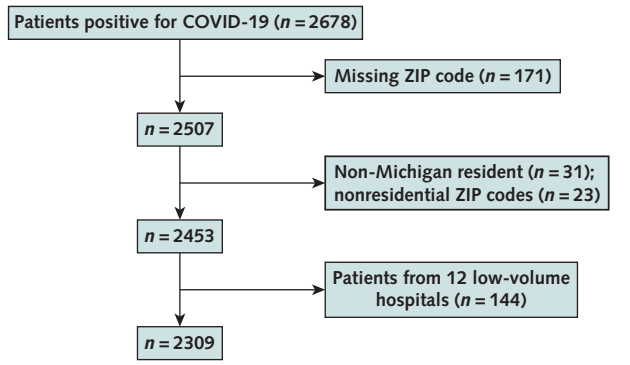
We performed a pooled cross-sectional study using data from patients hospitalized at 38 Michigan hospitals participating in a statewide collaborative quality improvement registry called MI-COVID19. Details regarding the MI-COVID19 registry (funded by the Blue Cross Blue Shield of Michigan/Blue Care Network of Michigan) have been previously published (10). This study was deemed "not regulated" by the University of Michigan Institutional Review Board (HUM00179611). In brief, trained abstractors collected data by reviewing patient medical records using a structured template. Patients were included in the study if they had either a positive COVID-19 test result during or up to 21 days before the hospital encounter; a negative COVID-19 test result during or up to 21 days before the hospital encounter with symptoms of cough, dyspnea, or fever or a discharge diagnosis of COVID-19 in the medical chart; or strong clinical suspicion of COVID-19 infection that was documented but could not be confirmed via testing because of logistic constraints. Patients were excluded if they were pregnant, were younger than 18 years, left against medical advice, entered comfort care or hospice within 3 hours of the hospital encounter, or had a length of stay greater than 120 days during the index encounter or if the patient discharge was within the 60-day follow-up window of a previously recorded or abstracted admission.

Sixty days after discharge, abstractors reviewed the medical records of patients to collect data on clinical events, including readmission (to the index hospital or any hospital viewable in the medical record) and post-discharge death. For this analysis, we excluded any patients who tested negative for COVID-19, who were discharged with an unconfirmed diagnosis of COVID-19, whose ZIP code was not within the state of Michigan, or who had a nonresidential ZIP code (for example, post office box). In addition, 144 patients from 12 participating hospitals with fewer than 25 patients with COVID-19 in the registry, classified as low-volume hospitals, were excluded from the main analyses. However, sensitivity analyses were performed including these patients, as noted in the following discussion. Figure 1 presents sample inclusion and exclusion criteria.

COVID-19 Hospitalization Outcomes

Our main COVID-19 outcomes included development of acute organ dysfunction, development of organ failure, use of invasive mechanical ventilation, intensive care unit stay, in-hospital death, and discharge disposition. Patients were classified as having acute organ dysfunction using the Centers for Disease Control and Prevention's Adult Sepsis Event definition as follows: acute renal dysfunction (creatinine level greater than 1.5 times baseline among patients without preexisting end-stage renal disease, where baseline is the lowest creatinine level during hospitalization); acute hematologic dysfunction (platelet count $<100 \times 10^9$ cells/L, with ≥50% decrease compared with baseline); and acute liver dysfunction (total bilirubin >34.2 μmol/L [>2.0 mg/dL], with ≥50% increase compared with baseline). Patients were classified as having acute organ failure if they died during hospitalization or received at least 1 of the following therapies: heated high-flow nasal cannula, noninvasive ventilation (bilevel positive airway pressure or continuous positive airway pressure), invasive mechanical ventilation, dialysis or renal replacement therapy, or vasopressor support.

Figure. Analytic cohort construction: patients with COVID-19 from Michigan hospitals.



Neighborhood Social Disadvantage

Clinical data abstracted from patient charts (for example, patient characteristics, intensive care unit status, clinical characteristics) were merged with the SVI to understand how neighborhood factors influenced COVID-19 outcomes. Developed by the Centers for Diseases Control and Prevention, the SVI provides a composite measure of community susceptibility to adversities in the face of health shocks and includes 4 subindices: socioeconomic status, household composition and disability, racial or ethnic minority status and language, and housing type and transportation (7). See Appendix Table 1 (available at Annals.org) for component measures for each subindex. The index is a percentile rank, ranging from 0 to 1, with higher values indicating greater social vulnerability or disadvantage. We transformed SVI reported at the census tract level into ZIP code level using a population-weighted average within each ZIP code. We hypothesized that patients from ZIP codes with higher SVI (that is, greater neighborhood disadvantage) would have poorer COVID-19 hospital outcomes. Thus, if neighborhood disadvantage effects on COVID-19 hospitalization outcomes are independent of individual patient clinical risk factors (for example, age, comorbid conditions), we would anticipate that SVI would be associated with poorer outcomes even after controlling for patient factors.

Covariates

Individual-level patient covariates included demographic characteristics (age, sex), baseline clinical characteristics

(Charlson comorbidity index), clinical measurements on hospital admission (pulse oximetry, respiratory rate), and time period of hospital admission (March through May 2020, June through August 2020, and September through December 2020, corresponding to dates of COVID-19 surges in Michigan). Selection of clinical measurements was based on our team's previous work identifying risk factors for hospital mortality (11), with the exception of creatinine level, owing to greater than 10% missingness of this variable in our sample.

Statistical Analysis

Descriptive statistics were used to describe the patient cohort living in a ZIP code with an SVI rating in the highest quartile compared with all others. To determine whether COVID-19 hospitalization outcomes were related to neighborhood SVI, mixed-effects logistic regression models were fit for each of the outcomes using melogit in Stata (StataCorp). The composite SVI and its subindices were included as a continuous variable in separate models to avoid multicollinearity.

Our primary models controlled for time using a categorical variable corresponding to the COVID-19 surges in Michigan and clinical patient factors associated with COVID-19 outcomes in addition to a hospital-level random intercept to account for within-hospital correlation. To disentangle the individual effect of patient ZIP code SVI from the cluster-level effect of hospitals, hospital-level mean SVI exposures were included in all models. Postestimation predictive margins were used to estimate the absolute risk for each outcome ("baseline" percentage) for a patient living in a ZIP code with an overall or subindex SVI score of 0.5 and the change in risk associated with an increase in the index by 0.25 (percentage point change for an increase of 1 quartile in the SVI).

To ensure rigor, sensitivity analyses were conducted by repeating the analyses in a subsample excluding patients admitted through hospital transfer, and the full sample including the patients from a low-volume hospital and transferred patients. Additionally, we also repeated the analysis using a logistic regression model with cluster robust standard errors in the main analytic sample excluding patients from low-volume hospitals. We estimated E-values as the degree of association or confounding, on the relative risk (RR) scale, between an unobserved variable and the outcome and between that variable and SVI, that would have to be present to explain away the differences in outcomes associated with SVI. The estimated confounding RRs, from 1.8 to 2.5, suggest that an unmeasured confounder not already represented by observed covariates would need to be moderate or large to produce these significant associations. We could not identify such large confounders, and our results are robust to this source of bias. All analyses were performed in SAS, version 9.4 (SAS Institute), and Stata, v16 (StataCorp), with α set at 0.05.

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Results

Data from 2678 patients with COVID-19 who were hospitalized between March and December 2020 were available. After exclusion criteria were applied, data from 2309 patients were included in the analysis. The distribution of the overall SVI index (median, 0.50; range, 0.04 to 0.96) and the 4 subindices, socioeconomic status (median, 0.48; range, 0.04 to 0.90), household composition and disability (median, 0.61; range, 0.07 to 0.99), minority status and language (median, 0.51; range, 0.08 to 0.92), and housing type and transportation (median, 0.55; range, 0.07 to 0.95) suggest significant variation in neighborhood social disadvantage. Similarly, the hospital mean SVI exposure for the overall SVI index (median, 0.48; range, 0.20 to 0.81) and the 4 subindices, socioeconomic status (median, 0.45; range, 0.28 to 0.74), household composition and disability (median, 0.63; range, 0.18 to 0.77), minority status and language (median, 0.51; range, 0.31 to 0.68), and housing type and transportation (median, 0.50; range, 0.19 to 0.79) also showed wide variability between hospitals in our sample. **Appendix Table 2** (available at Annals.org) shows the within-hospital variation among the participating hospitals along with the distribution of patients living in high- and low-vulnerability ZIP codes in the hospitals included in the analysis.

Patients living in high-vulnerability ZIP codes were younger, were more often Black or Hispanic, had more comorbid conditions, and more frequently had Medicaid insurance than patients in lower vulnerability ZIP codes (**Table 1**). These patients from high social vulnerability ZIP codes differed in pulse oximetry findings (5.4% in high-vulnerability vs. 3.5% in low-vulnerability ZIP codes had oxygen saturation ≤80%) and respiratory rate on admission (58.8% vs. 59.5%, respectively, had abnormal respiratory rates ≥20 breaths/min), compared with patients from other ZIP codes. Patients from high-vulnerability ZIP codes also more frequently were treated in the intensive care unit (29.0% vs. 24.5%), received mechanical ventilation (19.3% vs. 14.2%), and were discharged to home (62.1% vs. 60.1%). Compared with patients from low-vulnerability ZIP codes, those from high-vulnerability ZIP codes also had higher rates of acute organ dysfunction (51.9% vs. 48.6%), organ failure (54.7% vs. 51.6%), and in-hospital death (19.4% vs. 16.7%) in these unadjusted data.

Association Between Neighborhood Social Disadvantage and COVID-19 Outcomes

In mixed-effects regression analyses adjusting for individual patient clinical characteristics, time period, and mean hospital SVI exposure, a patient's neighborhood SVI was associated with receipt of mechanical ventilation, development of acute organ dysfunction, and development of acute organ failure. For example, a patient living in a ZIP code with an SVI of 0.5 such as Ludington, Michigan (a small harbor town in Northern

Table 1. Characteristics of Hospitalized Patients From High vs. Low SVI ZIP Codes

Patient Characteristics and Hospitalization Outcomes	Highest SVI* Quartile (*n* = 607)	Bottom 3 SVI* Quartiles (*n* = 1702)
Median age (IQR), *y*	63.5 (49.8–73.0)	65.6 (53.9–77.7)
Sex, *n (%)*		
Male	323 (53.2)	893 (52.5)
Female	284 (46.8)	809 (47.5)
Race/ethnicity, *n (%)*		
Black, non-Hispanic	435 (71.7)	522 (30.7)
White, non-Hispanic	99 (16.3)	928 (54.5)
Hispanic	45 (7.4)	104 (6.1)
Other	28 (4.6)	148 (8.7)
Median Charlson Comorbidity Score (IQR)	2.0 (0.0–3.0)	1.0 (0.0–3.0)
Pulse oximetry on admission, *n (%)*		
≤60%	7 (1.2)	8 (0.5%)
61%–70%	10 (1.6)	13 (0.8)
71%–80%	16 (2.6)	46 (2.7)
81%–90%	80 (13.2)	275 (16.2)
91%–100%	487 (80.2)	1347 (79.2)
Not available	7 (1.2)	13 (0.8)
Respiratory rate range on admission, *n (%)*		
Normal (<20 breaths/min)	239 (39.4)	656 (38.6)
Abnormal (20 breaths/min)	109 (18.0)	318 (18.7)
Abnormal (21 breaths/min)	10 (1.6)	23 (1.4)
Abnormal (22–24 breaths/min)	105 (17.3)	305 (18.0)
Abnormal (25–30 breaths/min)	78 (12.9)	229 (13.5)
Abnormal (>30 breaths/min)	55 (9.1)	139 (8.2)
Not reported	11 (1.8)	32 (1.9)
Insurance type, *n (%)*		
Commercial insurance	99 (16.3)	380 (22.3%)
Medicaid	111 (18.3)	180 (10.6)
Medicare	319 (52.6)	894 (52.5)
Other and self-pay	72 (11.9)	243 (14.3)
Outcomes, *n (%)*		
Developed acute organ dysfunction†	315 (51.9)	828 (48.6)
Developed organ failure‡	332 (54.7)	878 (51.6)
Received invasive mechanical ventilation	117 (19.3)	242 (14.2)
Received vasopressors	117 (19.3)	255 (15.0)
ICU care	176 (29.0)	417 (24.5)
In-hospital death	118 (19.4)	284 (16.7)
Discharge location, *n (%)*		
Home	377 (62.1)	1022 (60.1)
Facility (nursing home, rehabilitation, inpatient/residential hospice)	84 (13.8)	274 (16.1)
Month of admission, *n (%)*		
March–May 2020	533 (87.8)	1326 (77.9)
June–August 2020	44 (7.2)	233 (13.7)
September–December 2020	30 (4.9)	143 (8.4)

ICU = intensive care unit; IQR = interquartile range; SVI = social vulnerability index.

* The SVI is a summative measure of 4 subindices that are created using 2014–2018 American Community Survey 5-year estimates from the U.S. Census: socioeconomic status, household composition and disability, racial/ethnic minority status and language, and housing type and transportation. The overall SVI and each subindex is a percentile rank (range, 0 to 1), with higher values indicating greater social vulnerability/disadvantage. Data are reported at the Census tract level, which was population-weighted and transformed into ZIP code–level data using a crosswalk provided by the U.S. Department of Housing and Urban Development.

† COVID-19 cases were classified as involving acute organ dysfunction if patients received organ supportive treatment (i.e., any respiratory support, including supplemental oxygen, vasopressor therapy, or dialysis) or had laboratory evidence of acute organ dysfunction. Specifically, we identified the following acute organ dysfunctions based on a departure from the patients' baseline organ function, as consistent with the Centers for Disease Control and Prevention's Adult Sepsis Event definition: acute renal dysfunction (creatinine level >1.5 times baseline among patients without preexisting end-stage renal disease, where baseline is the lowest creatinine level during hospitalization); acute hematologic dysfunction (platelet count $<100 \times 10^9$ cells/L, with ≥50% decrease compared with baseline); and acute liver dysfunction (total bilirubin >34.2 μmol/L (>2.0 mg/dL), with ≥50% increase compared with baseline).

‡ COVID-19 cases were classified as involving acute organ failure if patients died during hospitalization or received at least 1 of the following therapies: heated high flow nasal cannula, noninvasive ventilation (i.e., bilevel positive airway pressure or continuous positive airway pressure), invasive mechanical ventilation, dialysis or renal replacement therapy, or vasopressor.

Michigan), was estimated to experience an absolute risk for mechanical ventilation of 14.7%, acute organ dysfunction of 48.8%, and acute organ failure of 52.1% (Table 2). In comparison, a patient living in a ZIP code in inner-city Detroit with an estimated increase in SVI by 0.25 (1 quartile above) had an increase in the risk for mechanical ventilation by 2.1 percentage points, acute organ dysfunction by 2.8 percentage points, and acute organ failure by 2.8 percentage points (Table 2).

Investigation of SVI subindices showed that patients living in a ZIP code with higher socioeconomic status

subindex scores (that is, lower socioeconomic status) were at higher risk for requiring mechanical ventilation (change in risk with increase in SVI by 0.25 [D_{risk}] = 2.3 percentage points) and developing acute organ failure (D_{risk} = 2.3 percentage points) compared with those living in areas with lower socioeconomic status subindex scores. Likewise, patients living in ZIP codes with higher household and disability subindex scores also experienced greater risk for developing acute organ dysfunction (D_{risk} = 3.3 percentage points) and acute organ failure (D_{risk} = 3.3 percentage points); whereas patients living in ZIP codes with higher minority status and language subindex scores had greater risk for developing acute organ failure (D_{risk} = 3.0 percentage points). The association of hospital SVI exposure on outcomes showed no significant association with COVID-19 outcomes across all models (**Appendix Table 3**, available at Annals.org).

Sensitivity Analysis

In a sensitivity analysis, we excluded all patients who were transferred from another hospital (n = 130); in another sensitivity analysis, we included patients from low-volume hospitals that were not included in the main analyses. The association between a patient's SVI and COVID-19 outcomes was attenuated in these models compared with our main specification (**Appendix Tables 4** and **5**, available at Annals.org). The population transferred to another hospital was notably more severely ill than the baseline population (**Appendix Table 4**). Additional sensitivity analyses in the full sample, which included patients from low-volume hospitals and patients who were transferred from another hospital, did not show any major differences from the study findings (**Appendix Tables 6** and **7**, available at Annals.org). An alternative analytic approach of logistic regression models with

Table 2. Association of Patient-Level Neighborhood Social Disadvantage With COVID-19 Hospitalization Outcomes (n = 2309)*

Independent Variable	Hospitalization Outcome					
	Organ Dysfunction	**Organ Failure**	**Mechanical Ventilation**	**ICU Stay**	**Death**	**Discharge to Home**
Overall SVI						
Absolute risk at the 50th percentile (95% CI), %	48.8 (45.0 to 52.7)	52.1 (48.2 to 56.0)	14.7 (11.7 to 17.7)	23.4 (19.1 to 27.7)	17.9 (14.7 to 21.1)	75.9 (72.8 to 78.9)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.8† (0.3 to 5.2)	2.8† (0.4 to 5.2)	2.1† (0.3 to 4.0)	1.6 (−0.5 to 3.7)	0.1 (−1.7 to 1.9)	1.1 (−1.0 to 3.2)
Socioeconomic status subindex						
Absolute risk at the 50th percentile (95% CI), %	49.1 (45.3 to 52.9)	52.3 (48.4 to 56.2)	14.8 (11.9 to 17.7)	23.5 (19.2 to 27.8)	17.8 (14.7 to 20.8)	76 (72.9 to 79.0)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.3 (0 to 4.5)	2.4† (0.1 to 4.6)	2.3† (0.5 to 4.0)	1.7 (−0.3 to 3.6)	0.3 (−1.4 to 2.0)	1.2 (−0.7 to 3.2)
Household characteristics and disability subindex						
Absolute risk at the 50th percentile (95% CI), %	49.4 (45.6 to 53.3)	52.6 (48.7 to 56.5)	15.2 (12.1 to 18.3)	24.0 (19.4 to 28.5)	17.8 (14.7 to 21.0)	76.2 (73.1 to 79.3)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	3.3† (0.7 to 6.0)	3.3† (0.7 to 5.9)	2.0 (−0.1 to 4.0)	1.6 (−0.7 to 3.9)	0.3 (−1.7 to 2.2)	1.9 (−0.4 to 4.1)
Racial/ethnic minority status and language subindex						
Absolute risk at the 50th percentile (95% CI), %	48.0 (44.0 to 51.9)	50.9 (47.0 to 54.9)	15.0 (11.7 to 18.3)	24.0 (19.4 to 28.6)	18.0 (14.5 to 21.5)	76.5 (73.2 to 79.7)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.7 (−0.4 to 5.7)	3.0† (0 to 6.0)	1.3 (−1.0 to 3.5)	0.5 (−2.0 to 3.0)	0.8 (−1.6 to 3.2)	-0.3 (−2.9 to 2.4)
Housing type and transportation subindex						
Absolute risk at the 50th percentile (95% CI), %	48.9 (45.1 to 52.6)	52.1 (48.3 to 56.0)	15.2 (12.1 to 18.3)	23.6 (19.4 to 27.8)	18.3 (14.9 to 21.8)	76.2 (73.1 to 79.2)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.2 (−1.5 to 5.8)	1.9 (−1.7 to 5.4)	1.3 (−1.4 to 4.0)	1.2 (−1.8 to 4.2)	−0.6 (−3.2 to 2.0)	0.3 (−2.9 to 3.5)

ICU = intensive care unit; SVI = social vulnerability index.

* Absolute risk and change in risk are estimated using postestimation predictive margins after fitting a mixed effects logistic regression. All models control for hospital-level mean SVI exposures and patient-level clinical covariates, including age, sex, Charlson score, respiratory rate range on admission, pulse oximetry range on admission, and time period of hospital admission (March through May 2020, June through August 2020, and September through December 2020) in the analytic sample. For example, the absolute risk for organ failure for a patient living in a neighborhood with an overall SVI score of 0.5 is 52.1%. An increase in SVI score from 0.5 to 0.75 increases the risk for organ failure by 2.8 percentage points.

† $P < 0.05$.

cluster robust standard errors also did not show any significant variation from our main findings, demonstrating the robustness of our methods.

DISCUSSION

In this multihospital study of patients hospitalized for COVID-19, we found that persons living in neighborhoods with greater social vulnerability were more likely to receive mechanical ventilation, experience acute organ dysfunction, and develop acute organ failure. These associations remained significant after adjustment for patient demographic and clinical characteristics, suggesting that much of the neighborhood social disadvantage effects we observed were independent of important individual-level factors related to patients' age and preexisting comorbid conditions. The association between patient ZIP code social vulnerability and COVID-19 hospitalization outcomes also remained significant after adjustment for hospital social vulnerability "case mix," suggesting that patients' neighborhood social disadvantage influences outcomes more than variation across hospitals caring for patients from high- versus low-vulnerability areas. Taken together, these findings suggest that patients' neighborhood social disadvantage affects hospital outcomes, including the need for mechanical ventilation and severity of organ dysfunction.

Our findings shed important light on the various contributors to racial and ethnic disparities in outcomes after COVID-19 hospitalization. Whether these disparities are driven by greater exposure risk due to housing, transportation, or other factors; greater susceptibility to infection after exposure; patients' underlying medical conditions; or differential access to care such that some people delay seeking care and consequently present to the hospital sicker remains unclear (4). Although several prior studies (including those performed by our group) (1–4) have found that patient race or ethnicity and social vulnerability are associated with higher overall COVID-19 mortality, we found no significant association between neighborhood social vulnerability and in-hospital mortality in this analysis (3, 5, 12–14). This observation echoes the conclusion of a recent systematic review by Mackey and colleagues (4) who (despite disparities in overall mortality) also reported no association between race, ethnicity, and case-fatality rates among those confirmed to have COVID-19. Our findings instead suggest that patients from socially vulnerable neighborhoods may present to the hospital in a sicker state, leading to more intensive care in the hospital. However, we find that once patients were hospitalized, neighborhood social factors did not influence outcomes of mortality and discharge disposition.

Our study adds to a growing literature examining the impact of structural racism on COVID-19 outcomes (15–17). For example, a recent study from Minnesota found that persons belonging to racial or ethnic minority groups had higher COVID-19 mortality rates than White persons, related to living in less advantaged neighborhoods as well as to higher residual mortality even when living within the same level of neighborhood disadvantage (18). Thus, both the Minnesota study and our Michigan study point to the importance of neighborhood-level disadvantage in COVID-19 outcomes, but the Minnesota study also supports the notion that systemic and structural inequalities experienced by persons in racial and ethnic minority groups cannot be elucidated by neighborhood contextual factors alone. Rather, policymakers must consider both individual social risks, such as poor-quality and segregated housing and difficulty accessing care, and neighborhood social risks, such as poor transportation networks, when devising strategies to mitigate the impact of COVID-19 in specific populations. Attention to these "upstream," prehospital aspects of health quality and health care delivery may offset "downstream" outcomes following hospitalization for COVID-19.

Our study has limitations, including a focus on hospitalizations in 1 state and the observational nature of the data. As well, potential missing documentation in chart abstraction and data reflecting trends related to changing COVID-19 variants remain a threat to inference. In addition, our study focuses on hospitalized patients and thus does not capture data from outpatient or postacute care sources, which may influence overall associations.

Despite these limitations, our study has important strengths, including a focus on type of care received during hospital admissions, not just rates of admission as examined in other studies (2–4, 19–28). Further, we add rigor by expanding from studies of single health care systems to a multihospital statewide cohort. By integrating data on individual patient clinical factors with neighborhood-level social disadvantage factors, we are able to understand not only aspects such as exposure to SARS-CoV-2 necessitating admission but also access to and experiences of health care once COVID-19 is suspected or diagnosed.

In conclusion, our findings demonstrate that hospitalized patients with COVID-19 from more socially vulnerable neighborhoods are more likely to present with greater illness severity and require more intensive treatment, but once hospitalized, they experience no differences in hospital mortality or discharge disposition. Policymakers should target more socially vulnerable neighborhoods to improve access to COVID-19 testing, treatment, and vaccination, as well as to identify and address social needs to ameliorate disparities in COVID-19 health outcomes.

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Appendix Table 1. SVI Components and Data Sources

SVI and Component Measures	Variable Detail	Original Data Source
Overall SVI	SVI	Centers for Disease Control and Prevention
Socioeconomic status index	Subdomain index of SVI that includes component measures below	Centers for Disease Control and Prevention
Poverty rate	Percentage of persons with income below the U.S. poverty level	2014–2018 American Community Survey
Unemployment rate	Percentage unemployed	2014–2018 American Community Survey
Income	Per capita income	2014–2018 American Community Survey
Educational attainment	Percentage of persons with no high school diploma (age ≥25 years) estimate	2014–2018 American Community Survey
Household characteristics and disability index	Subdomain index of SVI that includes component measures below	Centers for Disease Control and Prevention
65 years or older	Percentage of persons age 65 and older	2014–2018 American Community Survey
17 years or younger	Percentage of persons age 17 and younger	2014–2018 American Community Survey
Disability	Percentage of civilian noninstitutionalized population older than 5 years with a disability estimate	2014–2018 American Community Survey
Single parent household	Percentage of single-parent households with children younger than 18	2014–2018 American Community Survey
Minority status and language index	Subdomain index of SVI that includes component measures below	Centers for Disease Control and Prevention
Minority	Percentage minority (all persons except White, non-Hispanic)	2014–2018 American Community Survey
Limited English proficiency	Percentage of persons (age ≥5 years) who speak English "less than well"	2014–2018 American Community Survey
Housing type and transportation index	Subdomain index of SVI that includes component measures below	Centers for Disease Control and Prevention
Multiunit structure	Percentage of housing in structures with 10 or more units	2014–2018 American Community Survey
Mobile homes	Percentage of mobile homes	2014–2018 American Community Survey
Crowding	Percentage of occupied housing units with more people than rooms	2014–2018 American Community Survey
No vehicle	Percentage of households with no vehicle available	2014–2018 American Community Survey
Group quarters	Percentage of persons in institutionalized group quarters	2014–2018 American Community Survey

SVI = social vulnerability index.

Appendix Table 2. Variation of Patients' SVI Within the Participating Hospitals

Hospital	SVI Index			Quartiles of SVI Index, %			
	Median	Minimum	Maximum	1	2	3	4
1	0.85	0.11	0.91	1.7	6.9	13.8	77.6
2	0.83	0.43	0.92	0	2.3	34.1	63.6
3	0.77	0.28	0.86	7.5	8.8	25	58.8
4	0.77	0.11	0.94	8.7	4.4	34.8	52.2
5	0.77	0.18	0.92	5.6	0	30.6	63.9
6	0.75	0.24	0.9	18.6	15.1	14	52.3
7	0.7	0.14	0.87	4.2	11.3	43.7	40.9
8	0.65	0.14	0.9	21.2	19.7	19.7	39.4
9	0.64	0.17	0.86	11.6	24.2	26.3	37.9
10	0.61	0.23	0.81	10.5	18.4	47.4	23.7
11	0.61	0.16	0.81	5.9	11.8	73.5	8.8
12	0.61	0.14	0.81	14.1	25.8	33.6	26.6
13	0.58	0.18	0.93	5.4	17.1	39.6	37.8
14	0.56	0.15	0.91	20	11.4	40	28.6
15	0.54	0.18	0.79	2.8	54.9	38	4.2
16	0.53	0.08	0.75	10.8	48.7	35.1	5.4
17	0.53	0.21	0.83	14.3	42.9	38.8	4.1
18	0.53	0.1	0.81	18.5	45.7	27.8	8
19	0.5	0.07	0.9	38.7	17	19.8	24.5
20	0.47	0.33	0.81	0	64.3	28.6	7.1
21	0.44	0.07	0.95	42.9	28.6	17.5	11.1
22	0.41	0.08	0.92	35	23.3	17.2	24.6
23	0.35	0.11	0.91	49	25.5	16.3	9.2
24	0.34	0.08	0.79	35.1	40.4	22.2	2.2
25	0.32	0.07	0.95	59.5	12.2	1.4	27
26	0.25	0.11	0.95	79	8.1	6.5	6.5

SVI = social vulnerability index.

Appendix Table 3. Association of Hospital-Level Mean SVI Exposures With COVID-19 Hospitalization Outcomes in Analytic Sample (n = 2309)*

Independent Variable	Organ Dysfunction	Organ Failure	Mechanical Ventilation	ICU Stay	Death	Discharge to Home
Overall SVI						
Absolute risk at the 50th percentile (95% CI), %	49.4 (45.3 to 53.6)	52.8 (48.6 to 57.1)	14.4 (11.2 to 17.6)	22.9 (18.2 to 27.5)	17.1 (13.7 to 20.5)	75.6 (72.3 to 78.9)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−1.8 (−10.1 to 6.5)	−3.1 (−11.5 to 5.4)	4.6 (−2.5 to 11.7)	5.4 (−4.4 to 15.2)	6.0 (−1.6 to 13.5)	3.3 (−3.2 to 9.8)
Socioeconomic status subindex						
Absolute risk at the 50th percentile (95% CI), %	49.3 (45.4 to 53.3)	52.6 (48.6 to 56.6)	14.7 (11.7 to 17.7)	23.3 (18.8 to 27.7)	17.2 (14.1 to 20.4)	75.9 (72.8 to 79.0)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−1.9 (−9.0 to 5.3)	−2.7 (−10.0 to 4.6)	4.2 (−1.9 to 10.2)	4.6 (−3.9 to 13)	6.4 (−0.1 to 13.0)	2.8 (−2.9 to 8.4)
Household characteristics and disability subindex						
Absolute risk at the 50th percentile (95% CI), %	49.2 (45.4 to 53)	52.4 (48.6 to 56.3)	15.2 (12.1 to 18.4)	24.0 (19.5 to 28.5)	17.9 (14.7 to 21.1)	76.1 (73.1 to 79.1)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−4.4 (−12.3 to 3.5)	−4.8 (−12.9 to 3.3)	3.4 (−3.8 to 10.7)	1.8 (−7.7 to 11.2)	6.4 (−1.5 to 14.2)	1.5 (−4.9 to 7.8)
Minority status and language subindex						
Absolute risk at the 50th percentile (95% CI), %	52.2 (46.4 to 58.0)	56.1 (50.3 to 61.9)	18.8 (13.3 to 24.3)	26.1 (19.0 to 33.1)	20.6 (15.1 to 26.1)	75.6 (70.7 to 80.4)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−6.8 (−17.0 to 3.4)	−8.5 (−18.8 to 1.8)	−6.5 (−14.7 to 1.7)	−4.0 (−15.5 to 7.6)	−4.7 (−13.5 to 4.0)	1.6 (−6.8 to 10.1)
Housing type and transportation subindex						
Absolute risk at the 50th percentile (95% CI), %	48.8 (45.1 to 52.6)	52.1 (48.2 to 56.0)	15.1 (11.9 to 18.2)	23.3 (19.0 to 27.6)	18.3 (14.8 to 21.7)	76.1 (73.1 to 79.2)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	4.0 (−6.4 to 14.5)	2.3 (−8.4 to 13.0)	6.4 (−4.1 to 17.0)	10.4 (−3.4 to 24.2)	3.2 (−6.8 to 13.3)	2.6 (−5.5 to 10.6)

ICU = intensive care unit; SVI = social vulnerability index.

* Absolute risk and change in risk are estimated using postestimation predictive margins after fitting a mixed effects logistic regression. The absolute risk and the change in risk for hospital-level mean SVI exposures were derived from models investigating the association of patient-level neighborhood SVI with COVID-19 outcomes in the analytic sample, additionally controlling for patient-level clinical covariates including age, sex, Charlson score, respiratory rate range on admission, pulse oximetry range on admission, and time period of hospital admission (March through May 2020, June through August 2020, and September through December 2020).

Appendix Table 4. Association of Patient-Level Neighborhood SVI With COVID-19 Hospitalization Outcomes in Subsample Excluding Patients Transferred in From Another Hospital (*n* = 2179)*

Independent Variable	Organ Dysfunction	Organ Failure	Mechanical Ventilation	ICU Stay	Death	Discharge to Home
Overall SVI						
Absolute risk at the 50th percentile (95% CI), %	47.4 (43.6 to 51.2)	50.8 (46.9 to 54.6)	13.6 (11 to 16.2)	22.3 (18.3 to 26.4)	17.4 (14.2 to 20.6)	76.2 (73 to 79.3)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.5 (−0.1 to 5.1)	2.7† (0.1 to 5.2)	1.6 (−0.3 to 3.5)	0.7 (−1.4 to 2.9)	−0.5 (−2.4 to 1.3)	0.9 (−1.3 to 3)
Socioeconomic status subindex						
Absolute risk at the 50th percentile (95% CI), %	47.7 (43.9 to 51.4)	51.0 (47.1 to 54.9)	13.7 (11.1 to 16.2)	22.4 (18.3 to 26.4)	17.3 (14.2 to 20.3)	76.2 (73.1 to 79.4)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	1.9 (−0.5 to 4.4)	2.1 (−0.3 to 4.5)	1.8 (−0.1 to 3.6)	0.8 (−1.3 to 2.8)	−0.5 (−2.2 to 1.3)	0.9 (−1.1 to 2.9)
Household characteristics and disability subindex						
Absolute risk at the 50th percentile (95% CI), %	48.0 (44.2 to 51.7)	51.3 (47.4 to 55.1)	14.1 (11.3 to 16.9)	22.7 (18.5 to 27)	17.3 (14.2 to 20.4)	76.4 (73.2 to 79.6)
Change in risk with change in 25 percentile points (95% CI), *percentage point*	2.3 (−0.5 to 5.2)	2.5 (−0.3 to 5.3)	0.8 (−1.3 to 2.8)	−0.3 (−2.6 to 2.1)	−1.0 (−3 to 0.9)	1.8 (−0.5 to 4.1)
Minority status and language subindex						
Absolute risk at the 50th percentile (95% CI), %	46.4 (42.5 to 50.3)	49.5 (45.5 to 53.4)	13.8 (10.7 to 16.9)	22.8 (18.4 to 27.3)	17.2 (13.8 to 20.7)	76.8 (73.5 to 80.1)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	3.0 (−0.2 to 6.2)	3.4† (0.3 to 6.5)	1.5 (−0.9 to 3.9)	0.6 (−2 to 3.2)	1.4 (−1.1 to 3.9)	−0.6 (−3.3 to 2.1)
Housing type and transportation subindex						
Absolute risk at the 50th percentile (95% CI), %	47.4 (43.8 to 51)	50.8 (47 to 54.6)	14.1 (11.3 to 16.8)	22.5 (18.5 to 26.4)	17.8 (14.4 to 21.2)	76.4 (73.3 to 79.5)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.8 (−1 to 6.6)	2.7 (−1 to 6.4)	1.4 (−1.4 to 4.1)	1.5 (−1.7 to 4.7)	−0.6 (−3.3 to 2.1)	0.1 (−3.2 to 3.3)

ICU = intensive care unit; SVI = social vulnerability index.

* Absolute risk and change in risk are estimated using postestimation predictive margins after fitting a mixed effects logistic regression. All models control for hospital-level mean SVI exposures and patient-level clinical covariates including age, sex, Charlson score, respiratory rate range on admission, pulse oximetry range on admission, and time period of hospital admission (March through May 2020, June through August 2020, and September through December 2020).

† $P < 0.05$.

Appendix Table 5. Association of Hospital-Level Mean SVI Exposures With COVID-19 Hospitalization Outcomes in Subsample Excluding Patients Transferred in From Another Hospital (*n* = 2179)*

Independent Variable	Organ Dysfunction	Organ Failure	Mechanical Ventilation	ICU Stay	Death	Discharge to Home
Overall SVI						
Absolute risk at the 50th percentile (95% CI), %	47.8 (43.8 to 51.8)	51.4 (47.3 to 55.5)	13.1 (10.3 to 15.8)	21.5 (17.2 to 25.9)	16.5 (13.2 to 19.9)	75.9 (72.6 to 79.3)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−1.1 (−8.9 to 6.8)	−2.4 (−10.5 to 5.6)	5.6 (−0.8 to 12)	6.5 (−2.7 to 15.7)	6.6 (−0.8 to 14)	3.0 (−3.4 to 9.4)
Socioeconomic status subindex						
Absolute risk at the 50th percentile (95% CI), %	47.8 (44 to 51.6)	51.2 (47.3 to 55.1)	13.4 (10.8 to 16)	22.0 (17.9 to 26.2)	16.8 (13.7 to 19.9)	76.2 (73.0 to 79.3)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−1.3 (−8.2 to 5.5)	−2.2 (−9.3 to 4.8)	4.9 (−0.6 to 10.4)	5.5 (−2.5 to 13.6)	7.1† (0.6 to 13.6)	2.7 (−3.0 to 8.3)
Household characteristics and disability subindex						
Absolute risk at the 50th percentile (95% CI), %	47.7 (44.0 to 51.4)	51.0 (47.2 to 54.8)	14.1 (11.3 to 16.9)	22.9 (18.6 to 27.2)	17.5 (14.3 to 20.7)	76.4 (73.2 to 79.5)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−3.0 (−10.5 to 4.6)	−3.5 (−11.3 to 4.3)	4.8 (−2.0 to 11.7)	3.8 (−5.4 to 13)	7.8 (−0.1 to 15.7)	1.4 (−4.9 to 7.7)
Minority status and language subindex						
Absolute risk at the 50th percentile (95% CI), %	50.7 (44.9 to 56.5)	54.9 (49.1 to 60.7)	16.8 (11.7 to 22.0)	24.1 (17.4 to 30.8)	20.3 (14.8 to 25.9)	76.6 (71.6 to 81.6)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−6.5 (−16.7 to 3.7)	−8.6 (−18.9 to 1.7)	−4.7 (−12.7 to 3.2)	−2.2 (−13.5 to 9.1)	−5.2 (−13.9 to 3.6)	−0.1 (−9.1 to 8.8)
Housing type and transportation subindex						
Absolute risk at the 50th percentile (95% CI), %	47.4 (43.7 to 51.0)	50.8 (47.0 to 54.6)	13.9 (11.1 to 16.7)	22.1 (18.1 to 26.1)	17.7 (14.3 to 21.1)	76.4 (73.2 to 79.5)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	3.9 (−6.1 to 14.0)	2.0 (−8.3 to 12.4)	6.8 (−3.0 to 16.6)	10.1 (−2.9 to 23.1)	3.8 (−6.1 to 13.8)	2.9 (−5.0 to 10.9)

ICU = intensive care unit; SVI = social vulnerability index.

* Absolute risk and change in risk are estimated using postestimation predictive margins after fitting a mixed effects logistic regression. The absolute risk and the change in risk for hospital-level mean SVI exposures were derived from models investigating the association of patient-level neighborhood SVI with COVID-19 outcomes in the analytic sample, additionally controlling for patient-level clinical covariates including age, sex, Charlson score, respiratory rate range on admission, pulse oximetry range on admission, and time period of hospital admission (March through May 2020, June through August 2020, and September through December 2020).

Appendix Table 6. Association of Patient-Level Neighborhood SVI With COVID-19 Hospitalization Outcomes in Sample Including Patients From Hospitals Classified as Low Volume (n = 2453)*

Independent Variable	Organ Dysfunction	Organ Failure	Mechanical Ventilation	ICU Stay	Death	Discharge to Home
Overall SVI						
Absolute risk at the 50th percentile (95% CI), %	50.1 (46.5 to 53.6)	53.2 (49.6 to 56.8)	14.6 (11.9 to 17.3)	23.1 (19.3 to 26.9)	17.3 (14.2 to 20.4)	75.4 (72.2 to 78.6)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.6† (0.2 to 5.0)	2.6† (0.3 to 5.0)	2.3† (0.4 to 4.1)	1.9 (−0.2 to 3.9)	0.2 (−1.5 to 1.9)	1.1 (−1 to 3.1)
Socioeconomic status subindex						
Absolute risk at the 50th percentile (95% CI), %	50.3 (46.7 to 53.8)	53.4 (49.8 to 57.0)	14.7 (12.0 to 17.3)	23.1 (19.3 to 26.9)	17.2 (14.2 to 20.2)	75.5 (72.3 to 78.6)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.1 (−0.2 to 4.3)	2.1 (−0.1 to 4.3)	2.4‡ (0.6 to 4.1)	1.9 (−0.1 to 3.8)	0.3 (−1.3 to 1.9)	1.1 (−0.8 to 3.1)
Household characteristics and disability subindex						
Absolute risk at the 50th percentile (95% CI), %	50.5 (47 to 54.1)	53.7 (50.1 to 57.3)	14.9 (12.1 to 17.7)	23.4 (19.4 to 27.3)	17.2 (14.1 to 20.2)	75.6 (72.3 to 78.8)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	3.2† (0.6 to 5.8)	3.1† (0.6 to 5.6)	2.0† (0 to 4.0)	1.8 (−0.4 to 4.1)	0.3 (−1.6 to 2.1)	1.4 (−0.8 to 3.7)
Minority status and language subindex						
Absolute risk at the 50th percentile (95% CI), %	48.6 (45.0 to 52.2)	51.5 (47.9 to 55.1)	14.6 (11.6 to 17.5)	23.0 (18.9 to 27)	17.0 (13.7 to 20.3)	76.1 (72.9 to 79.2)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.7 (−0.2 to 5.7)	3.0† (0.1 to 5.9)	1.2 (−1.0 to 3.3)	0.6 (−1.8 to 3.0)	0.9 (−1.4 to 3.1)	0.4 (−2.2 to 3.0)
Housing type and transportation subindex						
Absolute risk at the 50th percentile (95% CI), %	50.1 (46.5 to 53.6)	53.2 (49.6 to 56.8)	14.9 (12.1 to 17.6)	23.0 (19.4 to 26.7)	17.5 (14.3 to 20.8)	75.7 (72.5 to 78.9)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	2.3 (−1.2 to 5.9)	2.0 (−1.4 to 5.5)	1.6 (−1.1 to 4.2)	1.7 (−1.3 to 4.7)	−0.4 (−2.9 to 2.0)	0.2 (−2.9 to 3.3)

ICU = intensive care unit; SVI = social vulnerability index.

* Absolute risk and change in risk are estimated using postestimation predictive margins after fitting a mixed effects logistic regression. All models control for hospital-level mean SVI exposures and patient-level clinical covariates including age, sex, Charlson score, respiratory rate range on admission, pulse oximetry range on admission, and time period of hospital admission (March through May 2020, June through August 2020, and September through December 2020).

† $P < 0.05$.

‡ $P < 0.01$.

Appendix Table 7. Association of Hospital-Level Mean SVI Exposure With COVID-19 Hospitalization Outcomes in Sample Including Patients From Hospitals Classified as Low Volume (n = 2453)*

Independent Variable	Organ Dysfunction	Organ Failure	Mechanical Ventilation	ICU Stay	Death	Discharge to Home
Overall SVI						
Absolute risk at the 50th percentile (95% CI), %	51.0 (47.3 to 54.7)	54.2 (50.4 to 57.9)	14.5 (11.7 to 17.4)	22.8 (18.8 to 26.7)	16.9 (13.7 to 20.0)	75.1 (71.8 to 78.4)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−5.3 (−12.6 to 2.1)	−5.6 (−13.1 to 1.8)	3.6 (−2.6 to 9.9)	4.8 (−3.7 to 13.3)	4.1 (−2.8 to 10.9)	4.0 (−2.3 to 10.3)
Socioeconomic status subindex						
Absolute risk at the 50th percentile (95% CI), %	50.6 (47.0 to 54.1)	53.7 (50.1 to 57.3)	14.6 (11.9 to 17.3)	22.9 (19.1 to 26.8)	16.9 (13.9 to 19.9)	75.4 (72.2 to 78.6)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−4.2 (−10.7 to 2.4)	−4.2 (−10.8 to 2.5)	3.7 (−1.8 to 9.3)	4.9 (−2.7 to 12.5)	5.3 (−1.0 to 11.5)	3.3 (−2.4 to 9.0)
Household characteristics and disability subindex						
Absolute risk at the 50th percentile (95% CI), %	50.2 (46.7 to 53.8)	53.4 (49.8 to 57.0)	15.0 (12.2 to 17.8)	23.4 (19.5 to 27.3)	17.2 (14.2 to 20.3)	75.6 (72.4 to 78.7)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−5.8 (−13.2 to 1.5)	−5.6 (−13.1 to 2.0)	2.5 (−3.9 to 9.0)	2.4 (−6.2 to 11.0)	4.8 (−2.6 to 12.2)	2.1 (−4.5 to 8.6)
Minority status and language subindex						
Absolute risk at the 50th percentile (95% CI), %	53.7 (49.4 to 58)	57.5 (53.2 to 61.7)	16.8 (13 to 20.5)	25.4 (20.5 to 30.2)	18.6 (14.7 to 22.5)	74.0 (70.1 to 77.9)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	−9.4† (−16.7 to −2.1)	−11.2‡ (−18.5 to −3.9)	−3.8 (−9.4 to 1.7)	−5.0 (−12.1 to 2.2)	−2.9 (−8.9 to 3.2)	5.1 (−1.0 to 11.2)
Housing type and transportation subindex						
Absolute risk at the 50th percentile (95% CI), %	50.1 (46.5 to 53.6)	53.2 (49.6 to 56.8)	14.8 (12.0 to 17.5)	22.7 (19.0 to 26.4)	17.5 (14.3 to 20.8)	75.7 (72.5 to 78.9)
Change in risk with change in 25 percentile points (95% CI), *percentage points*	1.2 (−8.4 to 10.8)	1.2 (−8.6 to 10.9)	5.9 (−3.3 to 15.0)	11.1 (−1.0 to 23.1)	0.8 (−8.0 to 9.5)	0.2 (−8.4 to 8.8)

ICU = intensive care unit; SVI = social vulnerability index.

* Absolute risk and change in risk are estimated using postestimation predictive margins after fitting a mixed effects logistic regression. The absolute risk and the change in risk for hospital-level mean SVI exposures were derived from models investigating the association of patient-level neighborhood SVI with COVID-19 outcomes in the analytic sample, additionally controlling for patient-level clinical covariates including age, sex, Charlson score, respiratory rate range on admission, pulse oximetry range on admission, and time period of hospital admission (March through May 2020, June through August 2020, and September through December 2020).

† $P < 0.05$.

‡ $P < 0.01$.