Association of community-level social vulnerability with US acute care hospital intensive care unit capacity during COVID-19

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A B S T R A C T

The COVID-19 pandemic has placed unprecedented stress on US acute care hospitals, leading to overburdened ICUs. It remains unknown if increased COVID-19 ICU occupancy is crowding out non-COVID-related care and whether hospitals in vulnerable communities may be more susceptible to ICUs reaching capacity. Using facility-level hospitalization data, we conducted a retrospective observational cohort study of 1753 US acute care hospitals reporting to the US Department of Health and Human Services Protect database from September 4, 2020 to February 25, 2021. 63% of hospitals reached critical ICU capacity for at least two weeks during the study period, and the surge of COVID-19 cases appeared to be crowding out non-COVID-19-related intensive care needs. Hospitals in the South (OR = 3.31, 95% CI OR 2.31–4.78) and West (OR = 2.28, 95% CI OR 1.51–3.46) were more likely to reach critical capacity than those in the Northeast, and hospitals in areas with the highest social vulnerability were more than twice as likely to reach capacity as those in the least vulnerable areas (OR = 2.15, 95% CI OR 1.41–3.29). The association between social vulnerability and critical ICU capacity highlights underlying structural inequities in health care access and provides an opportunity for policymakers to take action to prevent strained ICU capacity from compounding COVID-19 inequities.

With rising novel 2019 coronavirus disease (COVID-19) cases over the course of Fall and Winter 2020, hospitals increasingly became overburdened, leading to a critical shortage of intensive care unit (ICU) capacity. The ability of acute care hospitals to deliver timely, effective care is fundamental not just for patients with COVID-19 but for everyone else who relies on hospital care, and there is growing concern that escalation in COVID-19-related ICU admissions may be crowding out non-COVID-19 ICU care.

Tracking real-time data on hospital ICU care is critically important but has largely been unavailable at the individual hospital level, hampering our ability to fully understand how effectively our hospitals are able to manage the influx of patients. Prior studies have focused primarily on modeled projections of anticipated hospital capacity.[1,2] For the first time since the start of the pandemic, detailed hospital-level data on hospital capacity became available with the public release of the HHS Protect data on December 7, 2020. This opened up the possibility of assessing trends in ICU occupancy and the factors associated with hospitals exceeding a margin of safety and reaching critical occupancy.

There is reason to believe that capacity and strain will vary across hospitals. It may be that some types of hospitals—such as for-profit hospitals—are less likely to postpone elective surgeries, thus risking higher levels of ICU utilization. Additionally, there has been a disproportionate burden of COVID-19 infections on racial minority and economically vulnerable populations.[3–5] This disparity in infections has resulted in age-adjusted rates of COVID-19 hospitalization that are approximately four-fold higher for racial minority groups.[6] Already stressed hospitals located in communities serving a socially vulnerable population therefore may be even more likely to exceed ICU capacity, compounding underlying structural disparities in health care outcomes. Empirical data on the types of hospitals most likely to exceed capacity would be immensely helpful for policymakers to direct resources towards communities and hospitals at risk while mitigating disparities in COVID-19 care.

Using hospital-level ICU capacity data, we sought to answer three pressing policy questions. First, we examined trends and variation in ICU capacity during the third phase of the pandemic (Winter

2020–2021) across US hospital markets. Second, we examined the structural features of hospitals associated with reaching critical ICU capacity. Finally, we examined the relationship between community-level vulnerability and likelihood of hospitals reaching critical ICU capacity. We hypothesized for-profit hospitals, due to financial incentives, and hospitals in communities with high social vulnerability would be more susceptible to reaching or exceeding critical ICU capacity during the third phase of the COVID-19 pandemic.

1. Methods

1.1. Data

Data for this study covered the period from September 4, 2020 to February 25, 2021, and data were accessed on March 9, 2021. The HHS Protect Public Data Hub consolidates multiple data sources from HHS and CDC to create a dashboard of hospital capacity in the US in response to COVID-19.[7] Additionally, HHS requires all hospitals licensed to provide 24-h care to report data to the HHS Protect Effort. Initial dashboards were only at the state level, and due to delays, a hospital-level public dataset was not released until December 7, 2020. The HHS Protect hospitalization data file was merged with the 2018 American Hospital Association (AHA) Annual Survey using hospital CMS certification numbers (CCN) to obtain hospital-level structural features. The Area Health Resource File landscape file was then merged to the analytic dataset using county FIPS codes to obtain county-level socioeconomic variables.[8] Hospitals in the top decile of the disproportionate share index were defined as safety net hospitals. County-level Social Vulnerability Index (SVI) categorizations from the CDC were also linked to hospital data.[9] Data points smaller than 4 were suppressed by HHS and these hospital-week observations were excluded from analysis. 105 of the 4450 hospitals in the dataset did not have observations for all 25 weeks since September 1, 2020 and were excluded. Children's hospitals and long-term care hospitals were also excluded.

1.2. Variables

Our main dependent variable is a hospital reaching critical ICU capacity, which was defined as a hospital's ICU occupancy exceeding 90% for at least two weeks since September 4. We chose overall ICU occupancy for both COVID and non-COVID-related admissions as our main dependent variable as it reflects the effect of the burden of COVID-19 on the overall ability of acute hospitals to deliver timely and effective care for the sickest patients. Overall ICU occupancy has also emerged as an important gating criterion for re-institution of nonpharmacologic interventions such as restaurant closures or stay-at-home measures, and states including California have mandated cancellation of elective procedures when ICU occupancy exceeds the 90% threshold.[10] Hospital occupancy for each week was determined by dividing the number of occupied ICU beds by the number of staffed ICU beds.

Hospital-level variables explored for association with reaching critical ICU capacity included hospital size (less than 100 beds is small, 100–399 beds is medium, 400 or more beds is large), teaching status (non-teaching, major teaching, or minor teaching), profit status, safety net status, nurse-bed ratio, number of intensivists, number of operating rooms, and region. Safety-net was defined as the top decile of the disproportionate share (DSH) index which was obtained from the 2017 CMS Healthcare Cost Report Information System (HCRIS). Regions were divided using US Census Bureau categorizations as follows: Northeast, Midwest, South, and West.

Our main measure of community-level social vulnerability was the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI). The SVI assesses the ability of communities to respond to wide-scale hazardous events like natural disasters or disease outbreaks. The SVI represents a percentile ranking across US census tracts and is based on 15 social factors across the domains of socioeconomic status,

household composition, race/ethnicity/language, and housing/transportation (Supplemental Methods 1). SVI was aggregated at the county level, and these percentile rankings were categorized into quartiles.

1.2.1. Analysis

The unit of analysis was acute-care hospitals with unsuppressed ICU capacity data reported to HHS Protect over our study time frame. We first compared the characteristics of the HHS Protect sample to the overall sample of acute care hospitals in the AHA Annual Survey. Statistical testing of hospital characteristics was performed with chi-squared tests. ICU occupancy and capacity were aggregated across all hospitals and stratified by week and by region to determine national and regional trends of critical ICU capacity. Total and available ICU beds were aggregated within each Hospital Referral Region (HRR), as this geography represents a hospital market within which patients may be rebalanced between hospitals to prevent exceeding capacity. Given this rebalancing, we set the threshold for HRR critical capacity at 70% occupancy, based on observations that while hospitals often saw occupancy around 70% prior to the pandemic, few HRRs exceeded this 70% threshold (Supplemental Figure 1). We calculated the number of weeks during the third wave of the pandemic that each HRR exceeded 70% occupancy and displayed this data as a heatmap. We also aggregated capacity and occupancy data at the state level and ranked both HRRs and states by occupancy in the most recent week of data (February 19 to February 25).

We next assessed the relationship between hospital- and community-level factors and a hospital reaching critical ICU capacity. Mean values of hospital- and community-level factors were calculated independently for ICUs that did and did not exceed 90% occupancy for at least two weeks since September 1. In order to assess the relationship between hospital-level factors and a hospital reaching critical ICU capacity, we first compared bivariate relationships. We then created two multivariate logistic regression models to assess the relationship between hospital-level factors and a hospital reaching critical ICU capacity. The first model assessed the relationship between hospital structural features and the likelihood of a hospital reaching critical ICU capacity. Hospital features included hospital-level variables as described above. Given the regional waves of the pandemic, in the multivariate hospital characteristics model we included regional fixed effects to assess the relationship between hospital structural features and critical ICU capacity within a region. We then created an additional multivariate logistic regression model to assess the relationship of community-level vulnerability with critical ICU capacity, controlling for hospital structural features and regional fixed effects.

1.3. Sensitivity analysis

As a sensitivity analysis, we modeled the association between social vulnerability and critical capacity at the county and HRR level, given concerns that a hospital-level model does not capture the redistribution of patients within larger markets to avoid a specific hospital exceeding capacity (Supplemental Table 4). The number of staffed ICU beds and occupied ICU beds was summed for all hospitals within each HRR in each week to determine critical capacity, and HRRs were considered to have reached critical capacity if they exceeded 90% ICU occupancy for at least two weeks. In the county-level model, each county was assigned the critical-capacity status of the HRR in which it was located. In the HRR-level model, each HRR was assigned a social vulnerability score by calculating a population-weighted average of the SVI scores of each county in the HRR. County and HRR multivariable logistic regressions contained both social vulnerability and region, but not other hospital structural features as hospital-specific metrics like for-profit or safety-net status cannot necessarily be aggregated at larger geographies. We also assessed the relationship of each individual domain of the SVI by creating multivariate logistic regression models using each of the four sub-measures of SVI rather than the composite measure (Supplemental

Table 5) and controlling for hospital structural features. We also performed a mediation analysis by sequentially adding in covariates for hospital characteristics in addition to SVI (Supplemental Table 6). Analyses were performed using R Version 3.6.2. This study was exempt by the institutional review board of the Harvard T. H. Chan School of Public Health.

2. Results

A total of 4262 hospitals were included in the HHS Protect dataset, of which 1753 had unsuppressed ICU capacity data. Hospitals with less than 4 ICU beds were suppressed by HHS, so the resulting sample substantially underrepresented small and rural hospitals (Table 1). Critical access hospitals were especially affected by data suppression, with only 3 of 1256 critical access hospitals having available ICU capacity data.

From September 2020 to February of 2021, ICU occupancy increased across the US, though the upward trend was most substantial in the South, Midwest, and West (Fig. 1). In the South, ICU capacity increased by about 14% (30,720 to 35,103) from September to February while occupancy grew by 30% (22,752 to 29,533) resulting in overall occupancy growing from 74.1% to 84.1%. In the Midwest, capacity remained stagnant while occupancy surged through early December (11,129 to 14,396), bringing overall occupancy from 61.7% to 75.8% before declining to 71.1% by February. In line with this increasing overall occupancy, the proportion of hospitals in the Midwest with ICUs at critical capacity – defined as having more than 90% of beds occupied – more than tripled from 9% in September to 28% by the end of November. Though the Midwest saw declining critical capacity in December, the South (26%–54%), West (22%–46%) and Northeast (9%–19%) all saw the proportion of hospitals at critical ICU capacity increase from September through February before beginning to decline. Since

mid-October, much of this increase was driven by COVID-19 cases, with COVID-occupied ICU beds doubling in the South and increasing at more than twice that rate in other regions. Total ICU occupancy increased by considerably less in each region, and Fig. 1 highlights a clear decline in non-COVID ICU cases as the number of COVID patients rises and a corresponding rise in non-COVID ICU cases once the number of COVID patients begins to fall.

The distribution of US acute care hospitals reaching critical ICU capacity during the third wave of the COVID-19 pandemic shows substantial geographic variation (Fig. 2). Hospital referral regions (HRRs) in the South, Southwest, and portions of the Midwest were overburdened for the most weeks, while the Northeast and much of the West had limited experiences of critical capacity. In the most recent week of data (February 19 to February 25), the HRRs with the highest occupancies were Oxford, MS, Dothan, AL, Abilene, TX, St. Joseph, MI, and Temple, TX, all of which saw ICU occupancy at or above 98% of their reported ICU capacity (Supplemental Table 1). Similar results were observed when tabulating ICU occupancy by state, with only New Jersey dipping below 50% occupancy(Supplemental Table 2).

Of the 1753 hospitals with ICU occupancy data, 63% (1100) reached critical ICU capacity for at least two weeks since September, and these hospitals differed from those that did not reach critical capacity on a number of county- and hospital-level factors (Supplemental Table 3). In unadjusted bivariate analyses, for-profit status was associated with higher odds of critical ICU capacity (unadjusted OR 1.89, 95% CI OR 1.45–2.47, p < 0.001), while higher staffing for both nurses and intensivists was associated with lower odds of reaching critical ICU capacity (unadjusted OR 0.95,95% CI OR 0.92–0.98, p < 0.001 and unadjusted OR 0.89, 95% CI OR 0.83–0.95, p < 0.001, respectively Table 2). However, when adjusting for hospital structural features and controlling for the region, only the regional effect remained significant, suggesting the widespread regional effect of community-level transmission of COVID-19. In adjusted analyses, there was a statistically significant regional effect, with the South having over three times the odds (adjusted OR = 3.31, 95% CI OR 2.31–4.78, p < 0.001) of reaching critical capacity as those in the Northeast. Hospitals in the West also had increased odds (adjusted OR = 2.28, 95% CI OR 1.51–3.46, p < 0.001) of reaching critical capacity relative to those in the Northeast.

Social vulnerability was strongly associated with the odds of hospitals reaching critical ICU capacity in both unadjusted and adjusted models. Adjusting for hospital structural features and region, hospitals located in areas of the highest vulnerability had more than twice the odds of reaching critical ICU capacity as those in less vulnerable areas (adjusted OR 2.15, 95% CI OR 1.41–3.29, p < 0.001). When assessing critical ICU capacity at larger geographies, both counties and HRRs had higher odds of reaching critical ICU capacity when in more socially vulnerable areas (Supplemental Table 4).

When examining individual components of social vulnerability, minority status and socioeconomic vulnerability had the largest influence on odds of reaching critical capacity, while household composition and housing type were not significantly associated with critical capacity (Supplemental Table 5).

When sequentially adding additional control variables for hospital characteristics, odds of critical ICU capacity decreased for hospitals located in the highest vulnerability counties, but patterns were generally similar to our main results (Supplemental Table 6).

3. Discussion

In this analysis of official national acute-care hospital ICU occupancy data, approximately 3 in 5 hospitals were overburdened and reached critical ICU capacity, exceeding 90% occupancy for at least two weeks during the third phase of the COVID-19 pandemic. While hospital occupancy grew in all regions over the course of the study period, hospitals in the South and West were most likely to reach critical levels of ICU capacity. Most importantly, hospitals located in communities of the

Table 1
Characteristics of suppressed and unsuppressed hospitals.

	All Hospitals (%)	Hospitals without ICU Occupancy Data (%)	Hospitals with ICU Occupancy Data (%)	P-value
Total Hospitals	4269	2516	1753	
Size of Hospital				<0.001
Small	3122 (73.1%)	2365 (94.0%)	757 (43.2%)	
Medium	1050 (24.6%)	144 (5.7%)	906 (51.7%)	
Large	97 (2.3%)	7 (0.3%)	90 (5.1%)	
Teaching Status				<0.001
Non-Teaching	2943 (68.9%)	2110 (83.9%)	833 (47.5%)	
Minor Teaching	1090 (25.5%)	27 (1.1%)	209 (11.9%)	
Major Teaching	236 (5.5%)	379 (15.1%)	711 (40.6%)	
Region				<0.001
Northeast	533 (12.5%)	245 (9.7%)	288 (16.4%)	
Midwest	1304 (30.5%)	851 (33.8%)	739 (42.2%)	
South	1590 (37.2%)	922 (36.6%)	382 (21.8%)	
West	842 (19.7%)	498 (19.8%)	344 (19.6%)	
Rural Hospitals	1715 (40.2%)	1526 (60.7%)	189 (10.8%)	<0.001
Critical Access Hospitals	1256 (29.4%)	1253 (49.8%)	3 (0.2%)	<0.001

Hospitals with available ICU occupancy data are compared to Hospitals for which occupancy data was suppressed by HHS Protect due to privacy concerns.
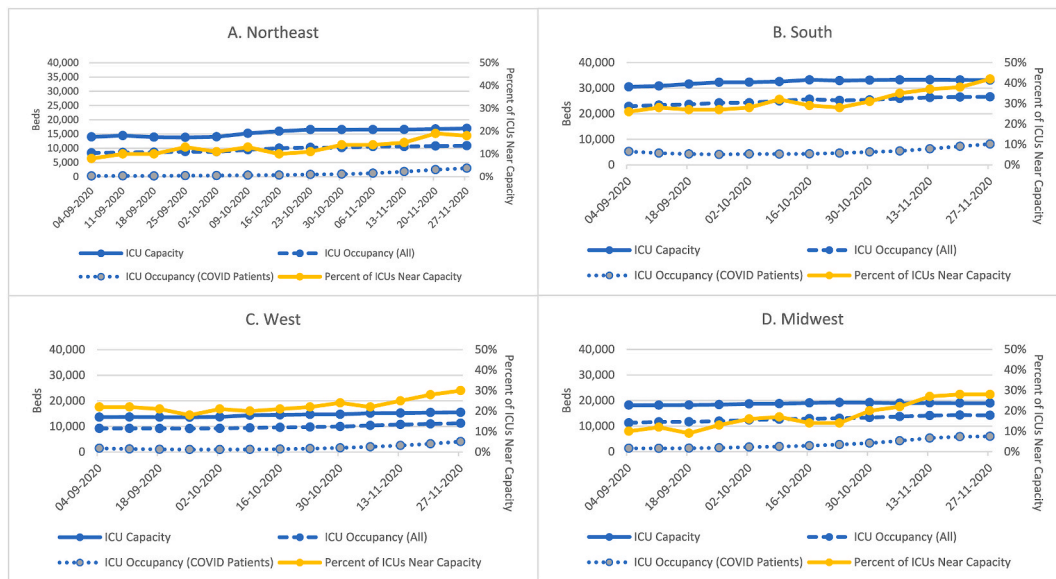
Fig. 1. Trend in Regional US ICU Occupancy and Capacity over the Third Phase of the COVID-19 Pandemic, September 2020 to February 2021
ICU occupancy and capacity from September 4, 2020 to February 25, 2020 are displayed stratified by region. The primary axis has units for overall ICU capacity and occupancy, as well as COVID and non-COVID occupancy. The secondary axis represents the percentage of ICUs at critical capacity.
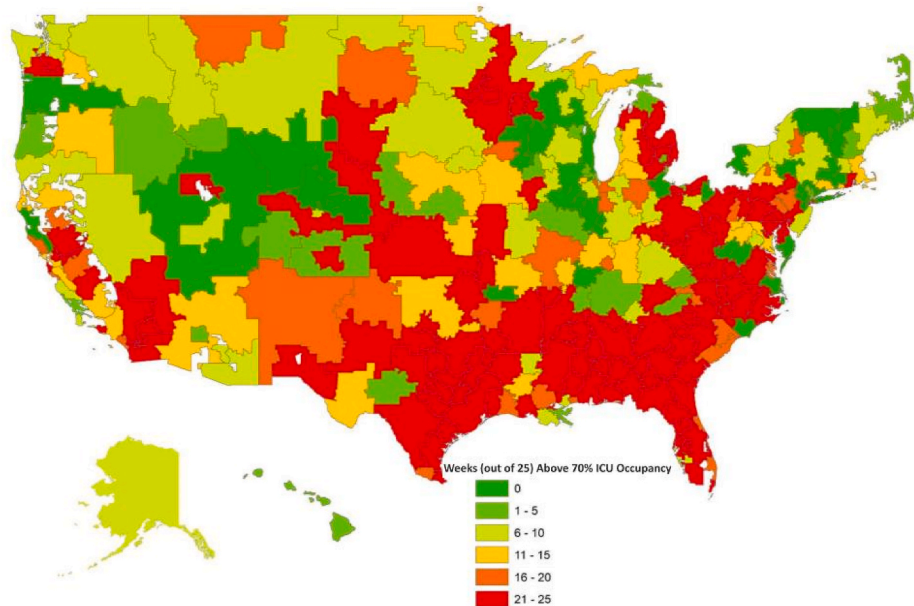

Fig. 2. HRR-Level Geographic Variation of Hospital ICU Occupancy Over the Third Wave of the COVID-19 Pandemic, Weeks with >70% Occupancy from September 2020 to February 2021
ICU occupancy aggregated at the Hospital Referral Region (HRR) and represents data from September 4, 2020 to February 25, 2021. HRR-level Critical ICU capacity is defined as hospital ICU occupancy >70%. HRRs in which all hospitals had data suppressed do not appear in this map.

highest social vulnerability had more than twice the odds of being overburdened. Taken together these findings highlight the disproportionate impact of COVID-19 cases on vulnerable communities, and in turn pose a concern that overburdened acute care hospitals may potentially be widening disparities of vulnerable populations by compounding structural inequities in access to medical care.

Other than regional variation, the strongest predictor of overburdened hospital ICUs was the county-level Social Vulnerability Index. Adjusting for age, racial and ethnic minority groups including Indigenous, Black, and Hispanic populations have approximately four-fold higher rates of hospitalization with COVID-19 compared to White, non-Hispanic persons.[6] This disproportionate burden is due in part to a higher prevalence of comorbidities as well as to socioeconomic determinants of COVID-19 exposure including household composition and occupational exposure.[11,12] In a study of Massachusetts municipalities,

the proportion of foreign-born noncitizens in a community, mean household size, and share of food service workers were strongly associated with higher COVID-19 rates.[3] Additionally, socially vulnerable communities have been shown to have higher rates of acute care hospital readmissions,[13,14] and the higher baseline need for acute care hospital services may serve as a second hit, placing already overburdened hospitals in these communities in a position to more likely reach potentially unsafe levels of ICU capacity during the pandemic.

There is a growing body of literature assessing the relationship between the SVI and COVID-19 case trajectory, suggesting that racial and ethnic disparities in COVID-19 cases may in large part be due to structural inequities in underserved communities.[4,15] Our study updates and extends this work by directly assessing the consequences of social vulnerability on hospitalizations and ICU capacity, which reflect both the underlying burden of COVID-19 as well as the inequitable access to

Table 2
Association between community variables and social vulnerability and critical ICU capacity.

	Unadjusted Odds of Critical ICU Capacity		Multivariate Adjusted Odds of Critical ICU Capacity	
	Odds Ratio (95% CI)	P Value	Odds Ratio (95% CI)	P Value
Size				
Small	Ref	Ref	Ref	Ref
Medium	0.82 (0.67, 1)	0.047	0.95 (0.71, 1.28)	0.744
Large	0.68 (0.44, 1.07)	0.093	0.8 (0.39, 1.65)	0.536
Teaching Status				
Non-Teaching				
Major Teaching	0.62 (0.45, 0.84)	0.002	0.89 (0.57, 1.41)	0.63
Minor Teaching	0.85 (0.69, 1.05)	0.123	0.92 (0.7, 1.21)	0.547
For Profit Hospitals	1.89 (1.45, 2.47)	<0.001	1.27 (0.86, 1.89)	0.231
Safety Net Hospital	1.36 (0.99, 1.9)	0.066	1.09 (0.71, 1.69)	0.685
Nurse-Bed Ratio	0.95 (0.92, 0.98)	<0.001	0.97 (0.93, 1.01)	0.128
Intensivists (per 10)	0.89 (0.83, 0.95)	<0.001	0.95 (0.88, 1.02)	0.175
Operating Rooms	1 (0.99, 1)	0.167	1 (0.99, 1.02)	0.431
Region				
Northeast	Ref	Ref	Ref	Ref
South	3.49 (2.63, 4.64)	<0.001	3.31 (2.31, 4.78)	<0.001
Midwest	1.23 (0.9, 1.67)	0.189	1.38 (0.95, 1.99)	0.092
West	3.05 (2.2, 4.25)	<0.001	2.28 (1.51, 3.46)	<0.001
Social Vulnerability in County				
Lowest SVI	Ref	<0.001	Ref	<0.001
Low SVI	1.45 (1.06, 1.97)		1.32 (0.9, 1.94)	
High SVI	1.96 (1.45, 2.63)		1.49 (1.02, 2.17)	
Highest SVI	3.53 (2.55, 4.92)		2.15 (1.41, 3.29)	

Bivariate and multivariable model of the association between critical ICU capacity and explanatory variables.

hospital-based acute care in socially vulnerable areas.[16] As ICU capacity has become a major determinant of COVID-19 risk-level for phased re-opening after state-mandated stay-at-home measures and lockdowns, our findings have immediate relevance for policymakers to target both pandemic response in the form of testing and vaccinations as well as economic relief to vulnerable communities suffering from the perfect storm of high COVID-19 cases, overburdened hospitals, and economic shutdown.

Although not significant in the multivariate analysis once controlling for community social vulnerability, there were meaningful hospital-level predictors of overburdened hospitals which may provide targeted opportunities to bolster support to hospitals. These structural features of hospitals may serve as mediators of the effect of community-level social vulnerability on hospital access, manifesting as decreased availability of in-hospital resources in more vulnerable communities. We identified an association between higher staffing for both nurses and intensivists and reduced odds of overburdened hospitals. Though the bottlenecks that ventilator and PPE supply placed on ICU capacity have largely been alleviated,[17,18] the American ICU capacity has still proved largely inelastic. One potential cause for this inelasticity is a shortage in the critical care workforce. A number of studies have documented worse outcomes in ICUs with lower nurse-patient ratios.[19,20] As the pandemic continues and healthcare worker burnout increases, ensuring adequate staffing remains an important clinical and policy priority. As detailed discharge and claim-level data become available, further research is needed to better identify if patterns of care varied by hospital type and across communities, allowing for an assessment of the potential spillover effects of COVID-19 on access to regular medical and surgical care.

4. Limitations

The HHS Protect hospitalization dataset suppresses small capacity and occupancy numbers, which leads to a substantial underrepresentation of rural and critical access hospitals. Our findings may underestimate the impact of rurality on hospital occupancy, and we were unable to analyze whether critical access hospitals had higher odds of reaching critical ICU capacity. Policymakers at HHS should release the full ICU and hospital occupancy data on rural and critical access hospitals, which are currently suppressed, to be able to ascertain the full consequences of overcrowded hospitals for rural communities. This study was conducted during the third wave of the pandemic during the Winter of 2020–2021, and our findings may not reflect patterns observed during later stages of the COVID-19 pandemic.

5. Conclusion

In conclusion, we find a substantial shortage of ICU capacity in the US, with approximately 3 in 5 hospitals in the US exceeding 90% occupancy for at least two weeks during the current wave of the COVID-19 pandemic. This growing crisis of overburdened ICUs has been driven by surging COVID-19 cases and has led to a reduction in non-COVID ICU care. Hospitals located in areas of high social vulnerability had more than twice the odds of being overburdened. Policymakers should ensure equitable access to hospital care by vulnerable populations during the pandemic. These findings can inform future pandemic preparedness and response efforts to support both vulnerable populations and the hospitals that serve them.

Author contributions

Conceptualization, TCT and AJ; Methodology, TCT, EJO, AKJ.; Software, BJH; Validation, TT, EJO, AKJ; Formal Analysis, TT and BHJ.; Investigation, TT and BHJ; Resources, TT and AKJ; Data Curation, TT and BHJ; Writing – Original Draft Preparation, TT and BHJ; Writing – Review & Editing, TT, BHJ, EJO, and AKJ; Visualization, BHJ; Supervision, TT and AKJ; Project Administration, TT; Funding Acquisition, TT.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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