Supplement: Supplementary Material*

Kadri SS, Sun J, Lawandi A, et al. Association between caseload surge and COVID-19 survival in 558 U.S. hospitals, March to August 2020. Ann Intern Med. 6 July 2021. [Epub ahead of print]. doi:10.7326/M21-1213

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* This supplementary material was provided by the authors to give readers further details on their article. The material was reviewed but not copyedited.

Methods

Data Curation Steps

Custom data extracts labeled "Premier™ Healthcare Database Special COVID-19 Release" were provided bi-weekly to investigators by the data provider granting access to their large file transfer site MoveIT by virtue of a data use agreement [No.75N90020P00477] between the National Institutes of Health and Premier Inc. These data are updated in near-real time with an approximate 2-3-week lag and processing time from date of discharge. The extract utilized in the analysis was accessed on November 9th, 2020, and included patients admitted January 1st, 2019 through those discharged October 31st, 2020 (Supplement Table 1). The rationale for this choice is provided in the "Handling of Missing Data" section below. Admission and discharge dates are only available at the month level with within-encounter events identifiable at the hospital day level.

Hospitalizations were selected by restricting to inpatient encounters admitted in March 2020 – August 2020. Continuously reporting hospitals were defined as those with at least one inpatient encounter in each month of January 2020 – August 2020. Additionally, to preserve statistical reliability, hospitals were restricted to those with at least 15 COVID-19 unique inpatient encounters between March – August 2020. COVID-19 diagnoses were defined by the codes in Supplement Table 1, an approach that has been previously validated using the same data source.(1) The characteristics of study hospitals were compared to excluded hospitals and non-federal U.S. hospitals (see Supplement Table 4).

Medication administrations were identified by searching verbatim for the name of the drug of interest within the billing file. Only medications that were considered to have a potential beneficial or potential harmful impact on outcomes in COVID-19 inpatients based on evidence at the time of conducting the study (October 1st 2020 to December 30th 2020) were selected for risk adjustment. Corticosteroids were captured as oral or parenteral administration of select agents in "Hormones, corticoids, plain" within the Chargemaster product class description. Hydroxychloroquine, azithromycin and remdesivir were all directly identified by name. Data on convalescent plasma, anticoagulation use and interleukin–6 inhibitors (e.g., tocilizumab) were not collected; convalescent plasma could not be distinguished from other similar blood products and lack of dosing information on certain anticoagulants made distinguishing prophylactic versus therapeutic intent challenging. Dopamine, epinephrine, norepinephrine, phenylephrine, vasopressin, angiotensin II were included in the vasopressor category.

Intensive care unit (ICU) utilization and type were accessed from the billing file searching verbatim for charges associated with the term "ICU" and this list was manually curated for plausibility by an investigator (SSK). Based on recommendations from the Centers for Medicare and Medicaid Services, alternative care sites(2) on the hospital campus (e.g. ICU-level care delivered in the hospital parking lot) could be considered a "brick-and-mortar" extension of the hospital. Care delivered at these alternative care sites could be billed for as though it was rendered in the traditional care setting (e.g. the actual ICU). This led to the assumption that our estimate of ICU–level care from billing files potentially captured such care rendered at alternative care sites during the pandemic. Mechanical ventilation was defined using the ICD-10

procedure codes 5A1935Z, 5A1945Z, 5A1955Z in conjunction with ICU admission charges on the same day of hospitalization to minimize inclusion of patients chronically ventilated at baseline (under the assumption that mechanical ventilation for acute indications in patients with COVID-19 at alternative care sites are likely to have been captured by the requirement of an ICU charge). Non-invasive positive pressure ventilation was determine using associated procedure codes and NIPPV use coded for obstructive sleep apnea or obesity hypoventilation syndrome was excluded to mitigate confounding due to chronic use. Elixhauser comorbidity code, utilized in sensitivity analyses, was determined using the R package ICD was utilized for calculation of the domain specific codes. The technologic index was created using relevant procedure codes and accommodation charges for extracorporeal membrane oxygenation, and continuous renal replacement therapy and accommodation charges for intensive care unit stays. The patient-to-attending physician ratio was calculated by capturing unique deidentified indicators for each physician-of-record among overall inpatients. Unique patient-level de-identified id numbers allow for restriction of analyses to the patient level. For those encounters with more than one admission in the same month, the discharge month and discharge sequence were used to identify the first in time. Of the pre-specified shrinking surge index percentile based categories, the 95-97.5%ile and 97.5-99%ile categories were combined into 95-99%ile post hoc for ease of presentation.

Data curation and statistical analysis R and SAS codes can be accessed on GitHub: https://github.com/sarahwarner/COVID-19-Surge-Impact-on-Mortality

Determination of Optimal Date of Near-Real-Time Data Extraction for Study Period
Near-real-time data extraction often yields incomplete counts for the end of a study period due to missing encounters due to longer stays without discharge dispositions at the time of data extraction or delayed data delivery by some hospitals. To mitigate this bias, the same data were queried on September 18, 2020, and November 9, 2020, as a quality control step to estimate the approximate lag time needed for plausible completeness of data in the final month of the study period. For the study, we used data accessed on November 9, 2020, rather than September 18, 2020 due to the lag time. This intentional lag time was chosen as it appeared to offer an optimal balance between data recency critical to the content being investigated and data completeness critical to preserve internal validity.

Supplement Table 1: Selection of Study Period and Optimal Representative Data Extract

2020 Admission Month	**N Inpatient Encounters**		**% Change from previous version**
	Accessed September 18, 2020	**Accessed** November 9, 2020	
January	607,314	658,697	9%
February	559,103	607,232	9%
March	510,774	553,108	8%
April	407,376	434,347	7%
May	448,040	489,050	9%
June	457,379	530,799	16%
July	325,250	533,579	64%
August	92,309	480,099	420%
September	--	319,348	--
October	--	67,077	--

Handling of Missing Data

Use of a version of the data that resulted in a lag period between the last admission and data release date (as shown in Supplement Table 1) considerably mitigated the missingness around encounters due to delayed reporting. Elimination of hospitals with <15 COVID-19 cases over the study period resulted in exclusion of 692 COVID-19 encounters. Elimination of hospitals without recorded ICU was essential to ensure cohort homogeneity with regard to provisions for severely ill patients with COVID-19. Elimination of these hospitals from the cohort resulted in exclusion of 2,813 COVID-19 encounters. Excluding encounters without reported gender resulted in exclusion of 125 COVID-19 encounters. Collectively these resulted in exclusion of <3% of all COVID-19 encounters (final study N=144,116 unique COVID-19 encounters at 558 hospitals). Imputation was not performed given the likely minimal impact of this degree of missing data on the overall analysis. However, despite the minimal loss of encounters of interest, these exclusion criteria resulted in exclusion of 237 (30%) of 795 continuously reporting hospitals, which may have resulted in the study cohort not necessarily being representative of overall database hospitals (see Supplement Table 4). The "previous month's COVID-19 caseload" variable for all March encounters was imputed as zero. Given the analysis was restricted to hospitals that reported continuously in each month between March and August 2020, we imputed absence of data on COVID-19 encounters in a given hospital month as a true absence of these cases.

Additional Details on Statistical Analyses

1. Generalized Linear Mixed Models (GLMM) were used to associate surge index to inpatient mortality or discharge to hospice.
2. A random effect for the hospital was included to account for within-hospital correlation of mortality.
3. Additionally, our models adjusted for the patients-level and the hospitals-level covariates.

In our hierarchical linear model, let i denote the i^{th} hospital and j denote the j^{th} COVID-19 patient admitted in the i^{th} hospital where $i = 1, \cdots I$ and $j = 1, \cdots, n_i$. Let Y_{ij} refer to the status of the j^{th} patient in the i^{th} hospital, which takes values of either 1 if a patient was deceased or discharged to hospice, and 0 if neither. Let X_{ijk} denote the k^{th} patient-specific covariates and Z_{il} denote the l^{th} hospital-specific covariates (see Supplement Table 4 for the complete list of covariates). Let V_{ij} be the surge index for the i^{th}hospital when the j^{th} patient was admitted. Then our generalized linear mixed model will be the following model:

$$\log\left(\frac{P(Y_{ij}=1)}{1-P(Y_{ij}=1)}\right) = \beta_0 + \sum_{k=1}^{K} X_{ijk}\beta_k + \sum_{l=1}^{L} Z_{il}\gamma_l + \varphi V_{ij} + h_i$$

where $\theta = (\beta_0, \beta_1, \cdots, \beta_K, \gamma_1, \cdots \gamma_L, \varphi)$ denote the fixed effect parameters that characterize the effects of covariates on likelihood of experiencing the events and quantify the deviation from overall mean β_0 and h_i be the random hospital effect which follows a $N(0, \sigma_h^2)$. Here, the random hospital effect accounts for the correlation between the patients admitted to the same hospital.

We used the SAS PROC GLIMMIX default, pseudo-likelihood method (RSPL) to fit the model. We set the "EMPIRICAL" option in the model statement to compute the *sandwich* estimator for the covariance matrix. Heteroscedasticity (e.g., greater variability in expected outcome among middle-aged COVID-19 patients versus those at extremes of age) was mitigated by this sandwich estimator, which is robust to misspecification of the variance-covariance matrix.(3) We tested the significance of the random hospital effect by the likelihood ratio chi-square test that follows a mixture of Chi-squared distribution. The corresponding p-value for our main model is <0.0001 implying the validity of using random hospital effects. The estimated variance of the random hospital effect for the primary model (Supplement Table 4) is 0.137 with standard error of 0.01366.

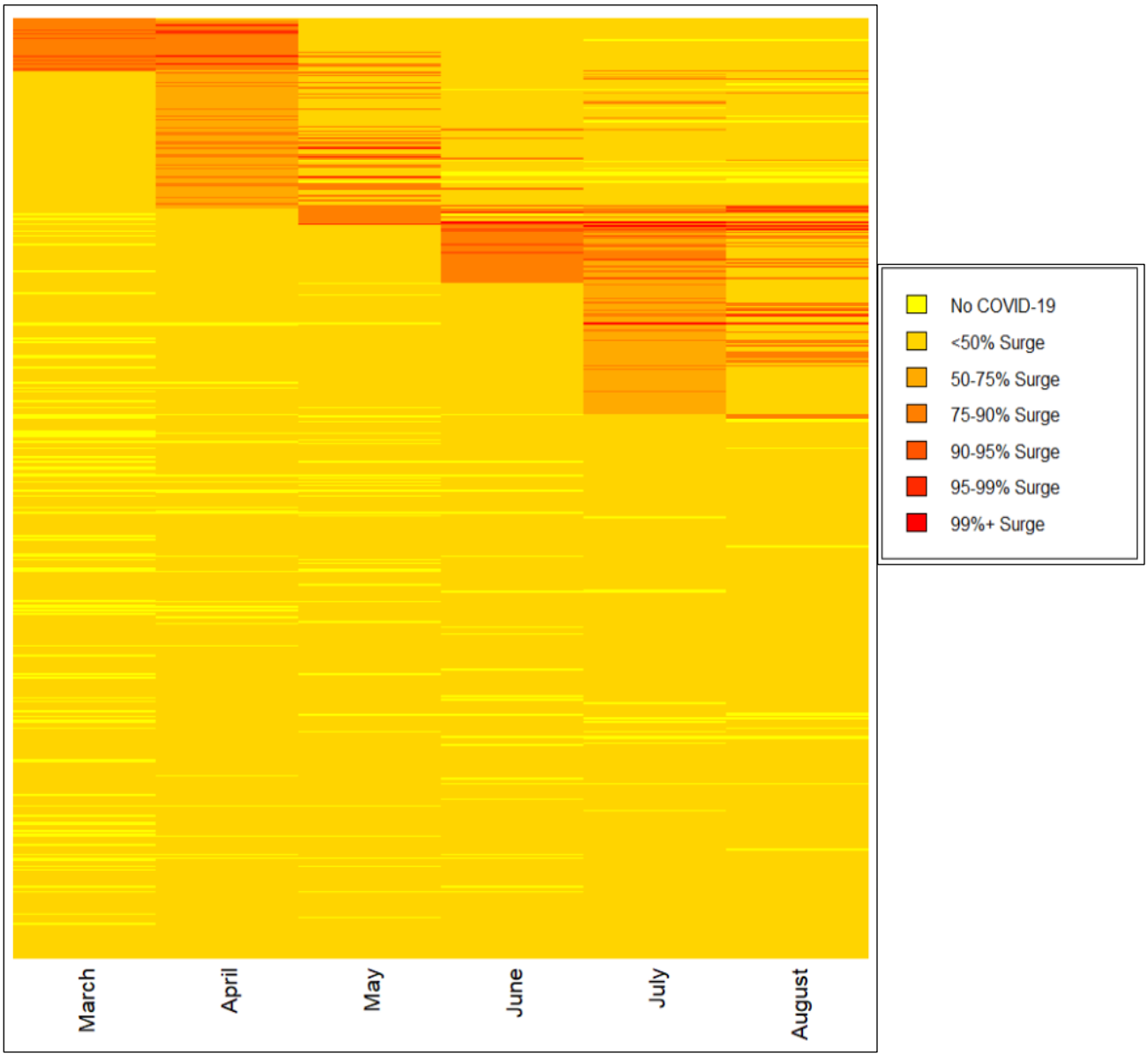
After confirming that a linear relationship fit the data well the surge index was also natural logarithm transformed for simpler assessment of interactions. To assess the impact of non-COVID caseload on the surge index–mortality relationship, a non-COVID index was calculated in a manner similar to the surge index for non-COVID (instead of COVID-19) caseload. We used SAS macro "margins" to estimate risk differences for estimating attributable deaths.

Supplement Table 2: Distribution of Hospital Characteristics, March 2020–August 2020

Hospital Characteristic	Study Hospital n (%) N=558	Hospitals with < 15 COVID-19 Encounters n (%) N=237	AHA US Non-Federal Hospitals* N=5141
Teaching hospital	190 (34.1)	31 (13.1)	2138 (41.6)
Urban Status:			
Urban	446 (79.9)	98 (41.4)	3336 (64.9)
Rural	112 (20.1)	139 (58.6)	1805 (35.1)
Geographic Region:			
Northeast	84 (15.1)	13 (5.5)	627 (12.2)
South	248 (44.4)	78 (32.9)	1984 (38.6)
Midwest	146 (26.2)	79 (33.3)	1538 (29.9)
West	80 (14.3)	67 (28.3)	992 (19.3)
Pre-COVID (2019) Bed Capacity:			
0-99	87 (15.6)	162 (68.4)	2888 (56.2)
100-199	131 (23.5)	41 (17.3)	952 (18.5)
200-299	115 (20.6)	16 (6.8)	515 (10.0)
300-499	137 (24.6)	13 (5.5)	489 (9.5)
500+	88 (15.8)	5 (2.1)	297 (5.8)
COVID-19 Technologic Index:			
Level 1–ECMO	108 (19.4)	3 (1.3)	--
Level 2–Multi-ICU, no ECMO	158 (28.3)	17 (7.2)	--
Level 3–Single ICU, CRRT	139 (24.9)	8 (3.4)	--
Level 4–Single ICU no CRRT	153 (27.4)	209 (88.2)	--

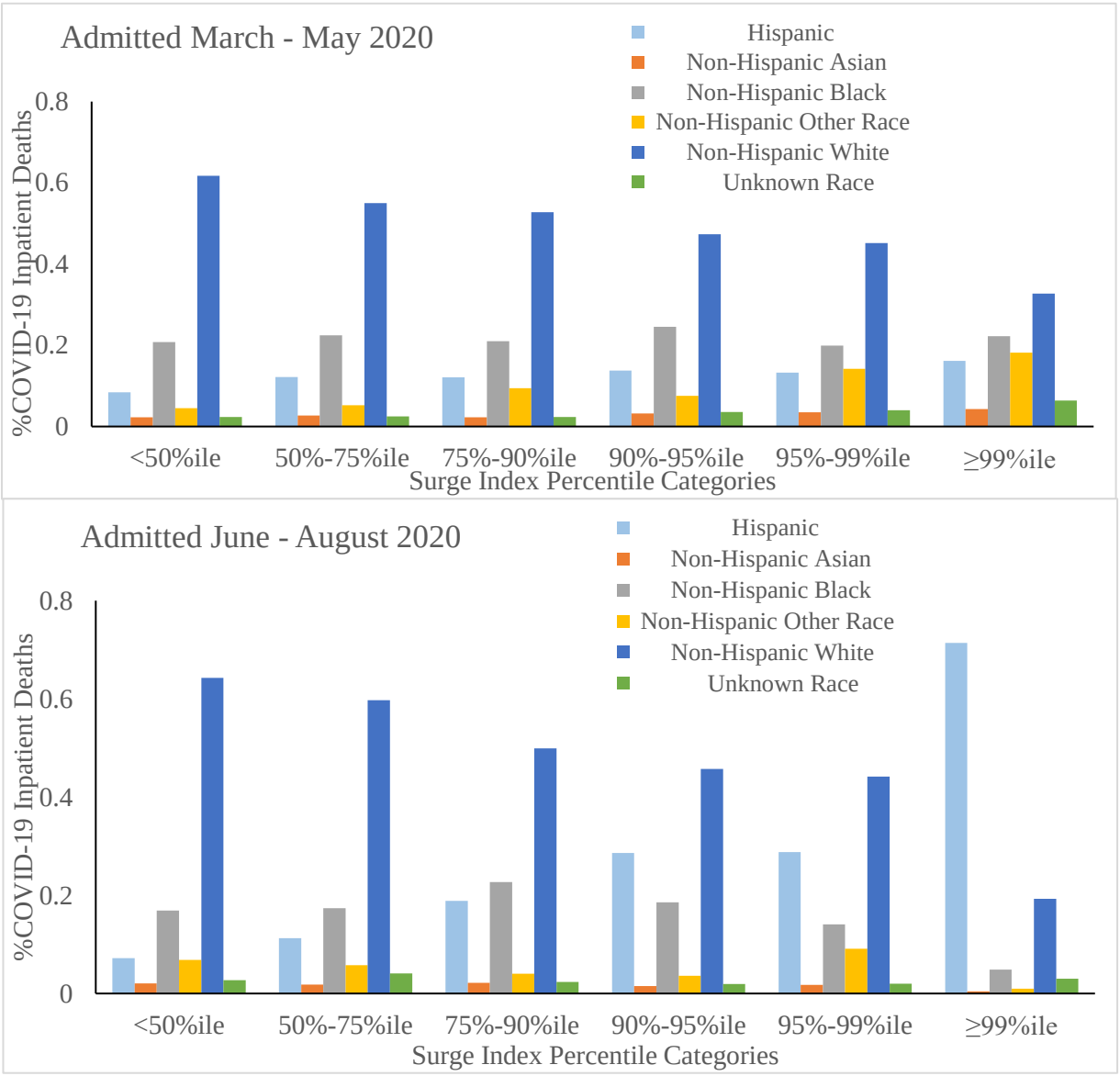
*2021 AHA Hospital Statistics; and AHA DataQuery based on FY2019 AHA Annual Survey Database. Chicago: Health Forum, an American Hospital Association affiliate, Feb. 2021.
AHA= American Hospital Association
COVID-19 = Coronavirus Disease 2019
CRRT=Continuous Renal Replacement Therapy
ECMO=Extracorporeal Membrane Oxygenation
ICU=Intensive Care Unit
IQR=Interquartile Range

Supplement Figure 1: Within-hospital distribution of Surge Index Percentile Category by Month, March–August 2020, 558 Hospitals



All 558 study hospitals (with at least 15 COVID-19 unique inpatient encounters each) are displayed with each row indicating one hospital and columns indicating month. Hospitals are organized by month of initial surge >50%, starting with March surge in the top left corner.
Heatmap displays the monthly distribution of a given hospital's COVID-19 surge index percentile category with light yellow indicating an absence of COVID-19 encounters during that hospital-month and intensity increasing to orange and proceeding to dark red as the surge index percentile category increases.

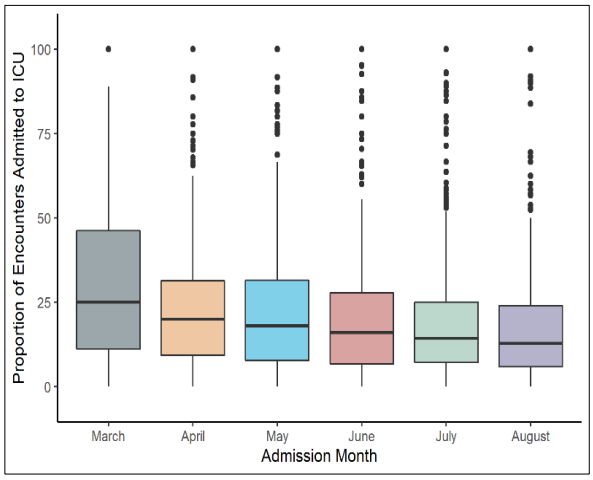
Supplement Figure 2: Distribution of COVID-19 Deaths by Race and Ethnicity, Surge Index Percentile Categories, and Month of Admission



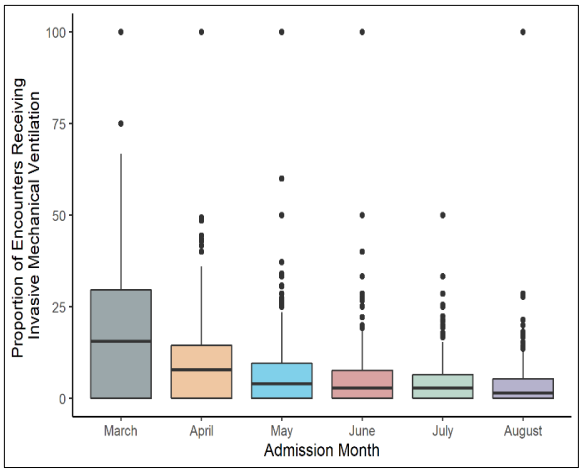
Bars are color coded for race and represent the proportional race and ethnicity distributions across inpatient COVID-19 deaths in the study cohort stratified by admission period and surge index category.

Supplement Figure 3: Utilization trends in supportive care for acute respiratory failure in COVID-19 on admission (+1 day)

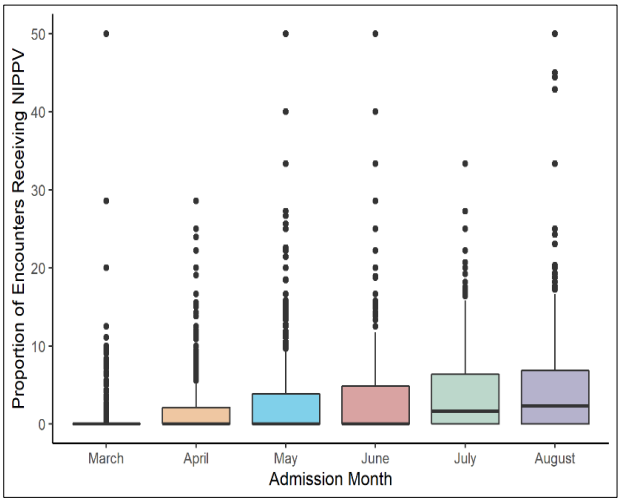
[A] ICU admissions



[B] Mechanical Ventilation



[C] NIPPV



Horizontal black lines represent median proportion, colored boxes represent the interquartile range, black vertical lines represent the upper 95% CI and dots represent outlier values.

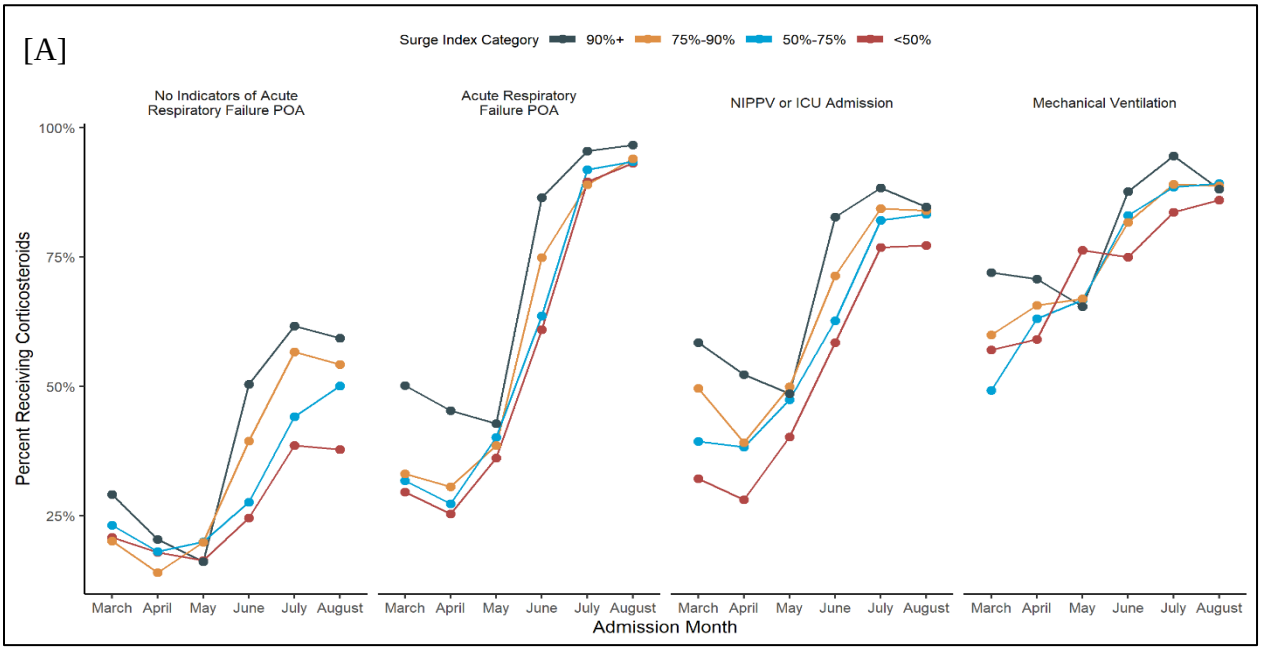
COVID-19 = Coronavirus Disease 2019
ICU= Intensive Care Unit
NIPPV=Non-invasive Positive Pressure Ventilation

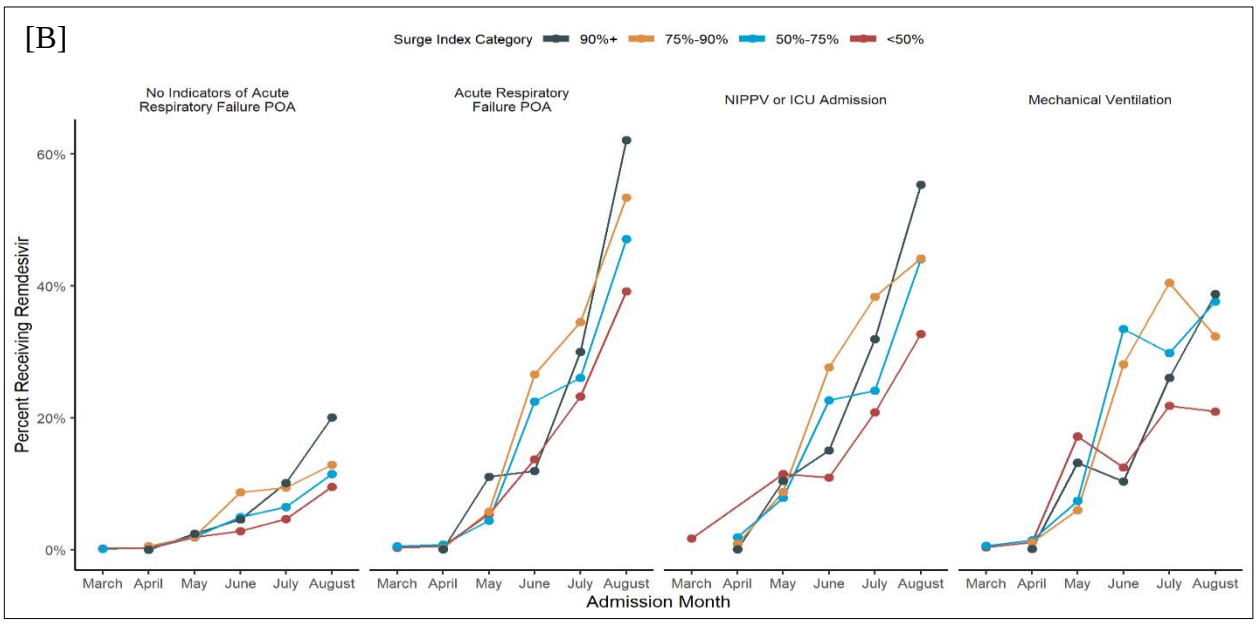
Supplement Table 3: Impact of Age, Timing of Admission, and Hospital Surge on Present on Admission Do-Not-Resuscitate Order

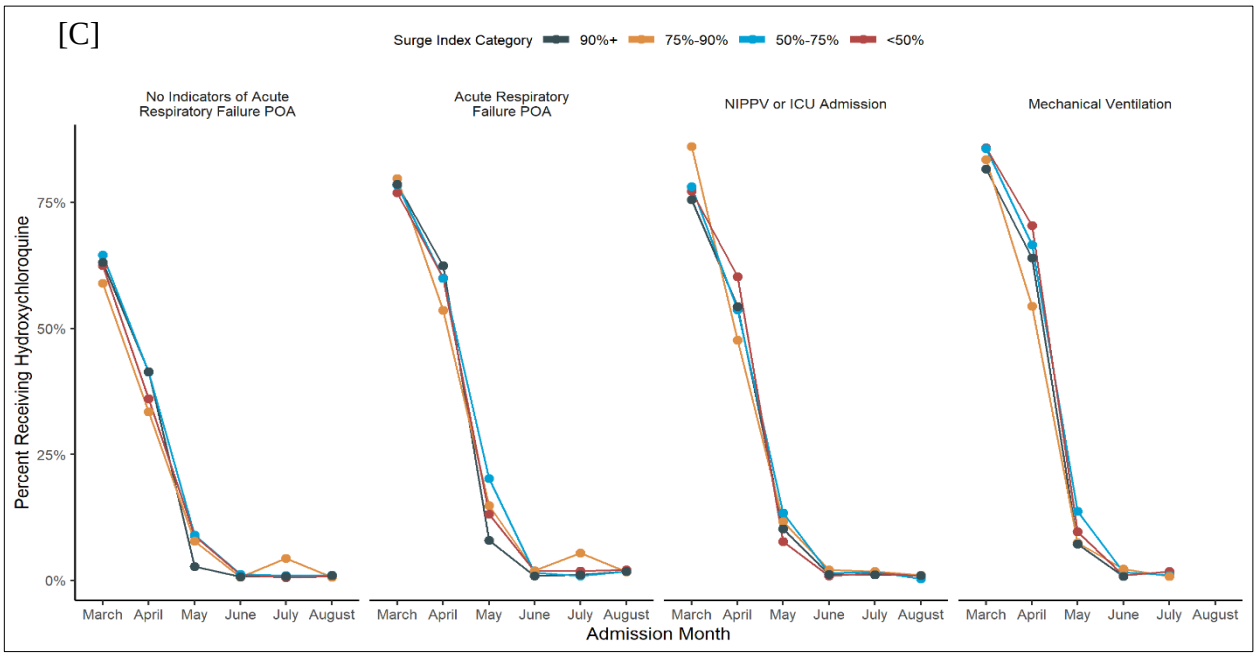
	Admitted March – May 2020					
	Percentile Categories (based on Hospital Months Ranked by Surge Index)					
Age Category	**<50%ile**	**50%-75%ile**	**75%-90%ile**	**90%-95%ile**	**95%-99%ile**	**≥99%ile**
<25	0 (0.0)	0 (0.0)	1 (0.4)	0 (0.0)	2 (0.8)	0 (0.0)
25-34	0 (0.0)	1 (0.2)	4 (0.5)	1 (0.2)	5 (0.7)	1 (0.1)
35-44	5 (1.3)	3 (0.4)	15 (1.3)	6 (0.8)	7 (0.6)	10 (0.6)
45-54	4 (0.6)	19 (1.5)	30 (1.7)	19 (1.7)	33 (1.5)	40 (1.5)
55-64	27 (2.8)	70 (3.8)	108 (4.2)	75 (4.3)	142 (4.7)	242 (5.1)
65-74	99 (10.1)	185 (10.3)	280 (11.4)	199 (11.3)	335 (11.7)	543 (11.0)
75-84	174 (24.4)	308 (22.6)	480 (24.3)	320 (25.2)	588 (25.6)	960 (23.2)
85+	217 (45.4)	423 (46.2)	701 (50.1)	462 (48.2)	893 (52.9)	1253 (46.7)

	Admitted June – August 2020					
	Percentile Categories (based on Hospital Months Ranked by Surge Index)					
Age Category	**<50%ile**	**50%-75%ile**	**75%-90%ile**	**90%-95%ile**	**95%-99%ile**	**≥99%ile**
<25	2 (0.6)	0 (0.0)	1 (0.2)	1 (0.3)	0 (0.0)	1 (0.6)
25-34	3 (0.5)	5 (0.4)	5 (0.3)	2 (0.2)	2 (0.2)	1 (0.3)
35-44	4 (0.6)	7 (0.4)	9 (0.4)	12 (0.9)	10 (0.6)	5 (0.9)
45-54	18 (2.1)	20 (0.9)	22 (0.8)	21 (1.1)	19 (0.8)	17 (1.8)
55-64	38 (3.4)	97 (3.3)	89 (2.5)	66 (2.6)	76 (2.4)	44 (3.8)
65-74	84 (7.1)	261 (8.4)	262 (7.0)	171 (6.8)	156 (5.2)	76 (6.7)
75-84	183 (18.7)	485 (20.2)	460 (16.5)	285 (15.5)	320 (14.4)	144 (15.9)
85+	240 (38.0)	615 (43.2)	568 (39.4)	387 (39.2)	407 (33.7)	129 (30.2)

Supplement Figure 4: Monthly Trends in the Proportion of Patients in each Surge Index Category Receiving [A] Systemic Corticosteroids, [B] Remdesivir, and [C] Hydroxychloroquine Stratified by Severity of COVID-19 Respiratory Failure, 558 U.S. Hospitals, March–August, 2020







The percentage of COVID-19 patients receiving remdesivir [A], hydroxychloroquine (with or without azithromycin) [B], or corticosteroids [C] at any time during their hospitalization are plotted by admission month (X axis), and surge index category (color of lines) and stratified by presenting severity of COVID-19 respiratory failure. Most severe COVID-19 respiratory failure is defined as those receiving invasive mechanical ventilation, followed by those requiring NIPPV or ICU Admission, followed by individuals coded for acute respiratory failure present on admission and no indicators of NIPPV, ICU admission, or invasive mechanical ventilation, and finally followed by those without any indicator of acute respiratory failure.

Legend:
[*]codes listed in online supplement
[†]occurring on hospital admission (+ 1 day); no indicator available in administrative data to specifically represent delivery of oxygen by high-flow nasal canula oxygen
[‡]occurring on hospital admission (+ 1 day)
[§]limited to encounters receiving ICU-level care

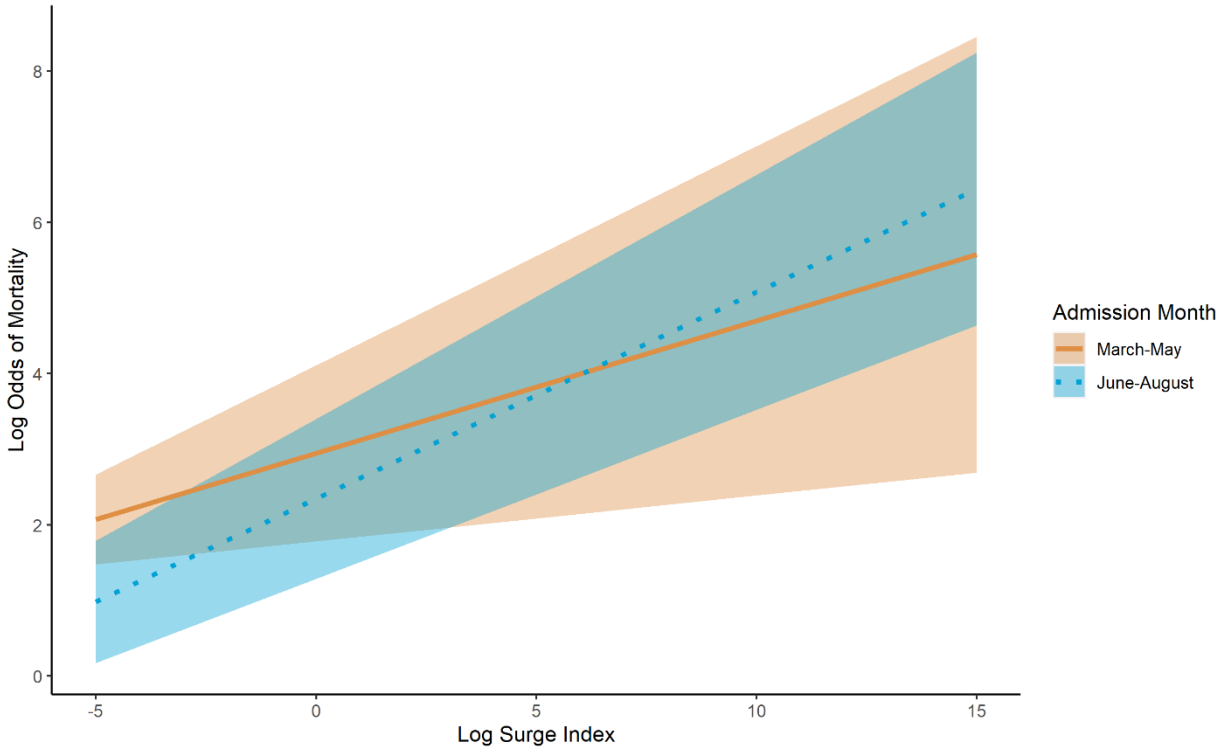
COVID-19 = Coronavirus Disease 2019
POA = Present on Admission
NIPPV = Noninvasive Positive-pressure Ventilation
ICU = Intensive Care Unit

Supplement Table 4: Adjusted Odds Ratio of Mortality (Primary Model), 558 U.S. Hospitals, March–August, 2020

Covariate	aOR (95% CI)
Primary Covariate	
Surge Index Category (percentile) [Ref: <50th percentile "non-surging"]	
50-75th	1.11 (1.01, 1.23)
75-90th	1.24 (1.12, 1.38)
90-95th	1.42 (1.27, 1.60)
95-99th	1.59 (1.41, 1.80)
99-100th	2.00 (1.69, 2.38)
Patient Encounter-level Secondary Covariates	
Age Category (in years) [Ref: 18-25 years]	
25-34	1.53 (1.12, 2.11)
35-44	2.07 (1.49, 2.89)
45-54	3.29 (2.38, 4.55)
55-64	5.44 (3.96, 7.48)
65-74	8.37 (6.03, 11.64)
75-84	13.55 (9.76, 18.80)
85+	22.26 (15.00, 30.0
Male Gender [Ref: Female]	1.24 (1.20, 1.29)
Race/Ethnicity [Ref: Non-Hispanic White]	
Hispanic	1.15 (1.07, 1.23)
Non- Hispanic Asian	1.048 (0.95, 1.15)
Non-Hispanic Black	0.97 (0.92, 1.02)
Non-Hispanic Other	1.04 (0.94, 1.15)
Unknown	1.26 (1.15, 1.38)
Admission Source [Ref: Home]	
Acute care hospital	1.38 (1.26, 1.50)
Other	1.00 (0.89, 1.12)
Subacute Facility	1.46 (1.34, 1.60)
Admission Type [Ref: Emergent/Urgent]	
Elective	1.12 (0.93, 1.35)
Other	0.74 (0.57, 0.96)
Primary Payer [Ref: Private Insurance]	
Medicaid	1.30 (1.21, 1.39)
Medicare	1.33 (1.24, 1.42)
Other	1.25 (1.10, 1.42)
Uninsured	1.48 (1.30, 1.68)
COVID-19 High-Risk Comorbidities* (POA)	
Cancer	1.75 (1.60, 1.92)
Stage 3 Chronic Kidney Disease	1.22 (1.16, 1.28)
Chronic Obstructive Pulmonary Disease	0.94 (0.90, 0.99)
Immunocompromised	1.08 (0.86, 1.37)
Obese/Overweight	1.19 (1.13, 1.25)
Pregnant	0.25 (0.14, 0.44)
Sickle Cell Disease	1.02 (0.62, 1.67)
Diabetes	1.05 (1.01, 1.08)
Asthma	0.76 (0.68, 0.86)
Interstitial Lung Disease	1.51 (1.30, 1.76)
Thalassemia	0.88 (0.51, 1.50)
Heart Disease	1.29 (1.24, 1.34)
Hypertension	0.95 (0.90, 0.99)
Other Neurologic Disease	1.37 (1.28, 1.48)
Liver Disease	1.22 (1.12, 1.34)
Acute Organ Failures on Presentation	
Severity Indicators of COVID-19 Acute Resp. Failure [Ref: no indicators]	
Acute Respiratory Failure Code POA†	1.27 (1.15, 1.41)
ICU Admission and/or NIPPV†,‡ on admission (+1 day)	2.27 (2.05, 2.51)
Invasive Mechanical Ventilation§ (+1 day)	3.46 (3.00, 4.00)
Vasopressor-dependent Shock (+1 day)	2.41 (2.20, 2.64)

Other AOFS‖-based Organ Failures (POA)	
Acute Hepatic Failure	2.18 (1.85, 2.58)
Acute Hematologic Failure	1.34 (1.26, 1.43)
Acute Metabolic Failure	1.76 (1.63, 1.83)
Acute Neurologic Failure	1.15 (1.05, 1.25)
Acute Renal Failure	1.56 (1.49, 1.63)
COVID-19 Medications Received	
Remdesivir	2.18 (1.85, 2.58)
Corticosteroids	1.34 (1.26, 1.43)
Hydroxychloroquine alone	0.96 (0.88, 1.06)
Azithromycin alone	0.97 (0.93, 1.03)
Hydroxychloroquine + Azithromycin concomitantly	1.04 (0.95, 1.14)
Do Not Resuscitate Order POA	3.53 (3.30, 3.77)
Admission Month in 2020 [Ref: March]	
April	0.64 (0.57, 0.72)
May	0.53 (0.46, 0.61)
June	0.39 (0.34, 0.46)
July	0.31 (0.26, 0.36)
August	0.27 (0.23, 0.32)
Hospital-Level Secondary Covariates	
Urban Hospital Location	1.02 (0.89, 1.18)
Teaching Hospital	0.84 (0.76, 0.92)
Hospital Bed Range [Ref: 00-99]	
100-199	1.45 (1.19, 1.76)
200-299	1.75 (1.43, 2.15)
300-399	1.65 (1.33, 2.05)
400-499	1.61 (1.26, 2.05)
500+	1.56 (1.24, 1.97)
Hospital Census Region [Ref: Midwest]	
Northeast vs Midwest	1.04 (0.90, 1.20)
South vs Midwest	1.18 (1.05, 1.33)
West vs Midwest	1.04 (0.91, 1.20)
Hospital Technical Index [Ref: Level–4[[Single ICU, no CRRT]	
Level–1[ECMO]	1.15 (0.99, 1.33)
Level–2[Multi-ICU]	1.09 (0.94, 1.25)
Level–3[Single-ICU, CRRT-equipped]	1.07 (0.94, 1.23)
Proportion of COVID-19 admissions receiving Invasive Mechanical Ventilation on admission (+1 day)	1.32 (0.30, 5.86)
Proportion of COVID-19 admitted to ICU on admission (+1 day)	0.30 (0.46, 0.77)
Remdesivir Available at Hospital During Month	1.07 (0.98, 1.16)
Ratio of Patients Mechanically Ventilated in 2019 v 2020	1.01 (0.94, 1.09)
Ratio of Patients per Attending-of-record	1.00 (1.00, 1.00)
Proportion of overall admission SARS-CoV-2 PCR-Tested	0.82 (0.69, 0.98)
Proportion of overall encounters Medicaid	2.31 (1.49, 3.59)
Proportion of overall encounters Uninsured	1.00 (0.98, 1.01)

*accessed on cdc.gov on 11/4/2020
†code listed in online supplement
‡no specific code available for high-flow nasal canula oxygen
§limited to encounters receiving ICU-level care
‖based on ICD-9 to ICD-10 conversion of codes that make up the Acute Organ Failure Score(4, 5)
COVID-19 = Coronavirus Disease 2019
POA = Present on Admission
AOFS = Acute Organ Failure Score
ICU = Intensive Care Unit
CRRT = Continuous Renal Replacement Therapy
ECMO = Extracorporeal Membrane Oxygenation
CDC = Centers for Disease Control



Supplement Figure 5: Impact of Interaction of Admission Month and Log Surge Index on Log Odds of Mortality, 558 U.S. Hospitals, March–August, 2020

This figure illustrates the interaction of Log surge index (as a continuous variable) and period of admission. June-August vs March – May 2020 slopes cross (slope difference=+0.10 [95% CI=+0.033-+0.16]) indicating a significant interaction.

Supplement Table 5: Log Surge Index and aOR of Mortality by Severity Indicators of COVID-19–related Respiratory Failure and Period of Admission

Variable	aOR Estimate	95% Confidence interval	
March-May Admissions			
No Acute Respiratory Failure Indicators	1.09	1.03	1.17
POA-Acute Respiratory Failure Code*	1.21	1.13	1.30
ICU or NIPPV† on admission (+1 day)	1.15	1.06	1.26
Invasive Mechanical Ventilation‡ (+1 day)	1.29	1.15	1.44
June-August Admissions			
No Acute Respiratory Failure Indicators	1.22	1.12	1.33
POA-Acute Respiratory Failure Code*	1.33	1.21	1.46
ICU or NIPPV† on admission (+1 day)	1.30	1.20	1.40
Invasive Mechanical Ventilation‡ (+1 day)	1.24	1.08	1.43

*code listed in online supplement

†no specific code available for high-flow nasal canula oxygen

‡limited to encounters receiving ICU-level care

ICU = Intensive Care Unit; NIPPV = Noninvasive Positive-pressure Ventilation; POA = Present on Admission

Supplement Table 6: Pairwise Interactions by Surge Attributes in each Admission Period, 558 U.S. Hospitals, March–August 2020

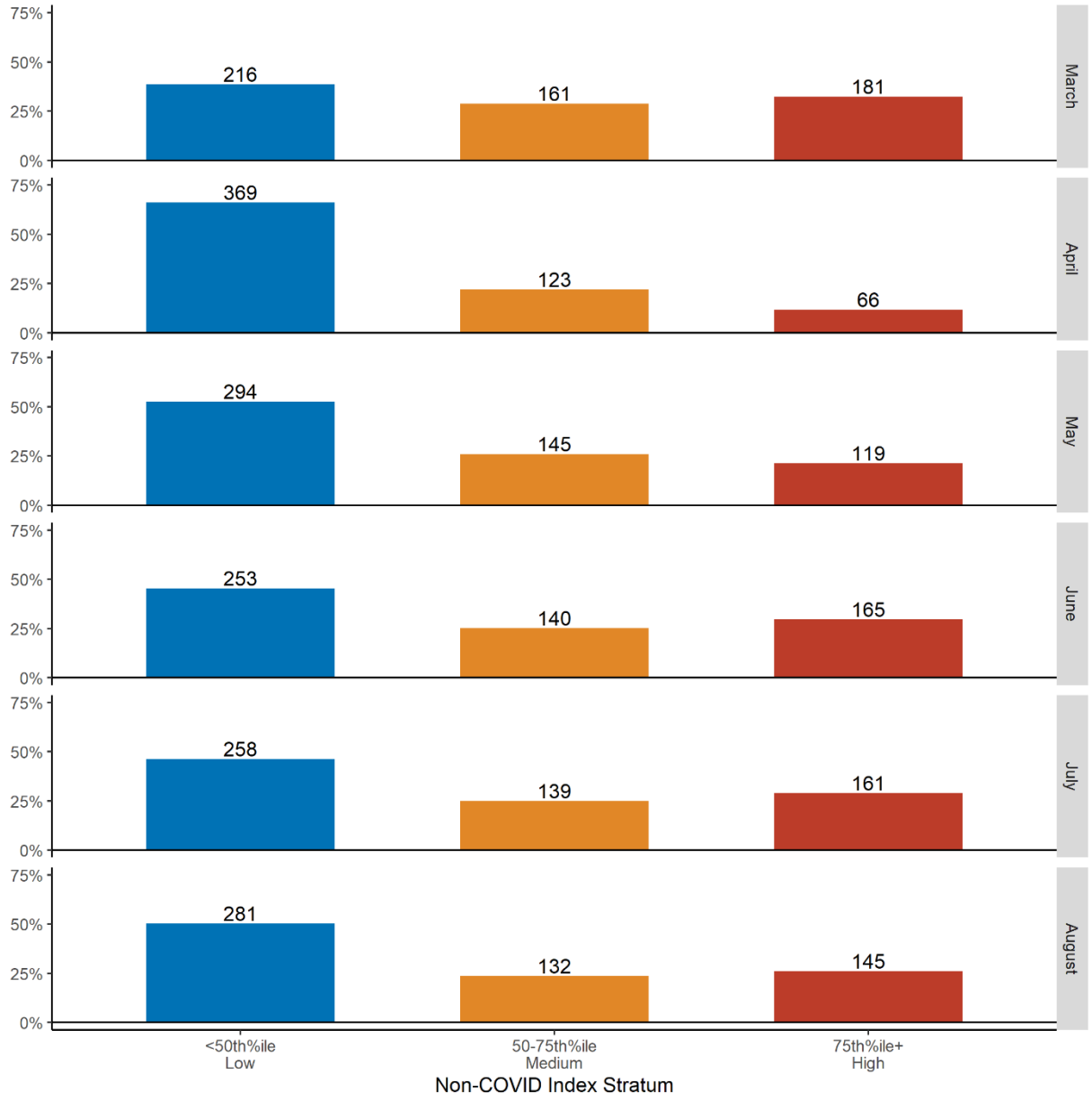
Admission Month in 2020	Comparison Cohorts	Slope Difference	95% Confidence Interval
March – May	**No indicators vs Acute Respiratory Failure***	-0.101	(-0.1685, -0.03358)
	No indicators vs ICU Admission or NIPPV	-0.05298	(-0.1393, 0.03332)
	No indicators vs Mechanical Ventilation*	-0.1625	(-0.2664, -0.05859)
	Acute Respiratory Failure vs ICU Admission or NIPPV	0.04807	(-0.04106, 0.1372)
	Acute Respiratory Failure vs Mechanical Ventilation	-0.06143	(-0.1699, 0.04708)
	ICU Admission or NIPPV vs Mechanical Ventilation*	-0.1095	(-0.2031, -0.01591)
June – August	No indicators vs Acute Respiratory Failure	-0.08729	(-0.18, 0.005393)
	No indicators vs ICU Admission or NIPPV	-0.05956	(-0.1441, 0.02498)
	No indicators vs Mechanical Ventilation	-0.01791	(-0.1737, 0.1379)
	Acute Respiratory Failure vs ICU Admission or NIPPV	0.02773	(-0.06573, 0.1212)
	Acute Respiratory Failure vs Mechanical Ventilation	0.06938	(-0.06279, 0.2015)
	ICU Admission or NIPPV vs Mechanical Ventilation	0.04165	(-0.09621, 0.1795)
March – May	Prior Month Surge (>=50%) vs Prior Month Non Surging (<50%)	-0.00543	(-0.08278, 0.0719)
June – August	**Prior Month Surge (>=50%) vs Prior Month Non Surging (<50%)***	**0.1784**	**(0.04564, 0.3112)**
March – May	Medium vs No Non-COVID Caseload	0.05176	(0.1388, -0.03529)
	High vs No Non-COVID Caseload	-0.05498	(-0.1389, 0.0289)
	High vs Medium Non-COVID Caseload	-0.1067	(-0.2195, 0.006057)
June – August	Medium vs No Non-COVID Caseload	-0.01449	(-0.1122, 0.08324)
	High vs No Non-COVID Caseload	-0.02594	(-0.1351, 0.08324)
	High vs Medium Non-COVID Caseload	-0.01146	(-0.1136, 0.09064)
March – May	Northeast vs Midwest	0.1081	(-0.00307, 0.2193)
	South vs Midwest	0.06432	(-0.04952, 0.1782)
	West vs Midwest	0.007133	(-0.178, 0.1922)
	South vs Northeast	-0.04379	(-0.1419, 0.05432)
	West vs Northeast	-0.101	(-0.28, 0.07807)
	West vs South	-0.05719	(-0.2293, 0.1149)
June – August	Northeast vs Midwest	-0.04321	(-0.3045, 0.2181)
	South vs Midwest	0.06466	(-0.1087, 0.238)
	West vs Midwest	0.09211	(-0.0936, 0.2778)
	South vs Northeast	0.1079	(-0.1258, 0.3415)
	West vs Northeast	0.1353	(-0.104, 0.3747)
	West vs South	0.02745	(-0.1028, 0.1578)

*statistically significant slope difference. A positive value for the slope difference suggest net difference is upsloping and vice versa. For example, a slope difference estimate of 0.2076 for high vs low prior month surge suggests the log surge index-mortality relationship was stronger for hospitals that had high (vs low) caseload surge in the previous month and positive upper and lower 95% CI bound for the estimate indicates the interaction was statistically significant.
Note: No surge is defined as <50th percentile, medium represents 50-75th percentile and high suggests >75th percentile. Non-COVID caseload was severity weighted and adjusted for baseline bed capacity in a manner similar to the surge index.

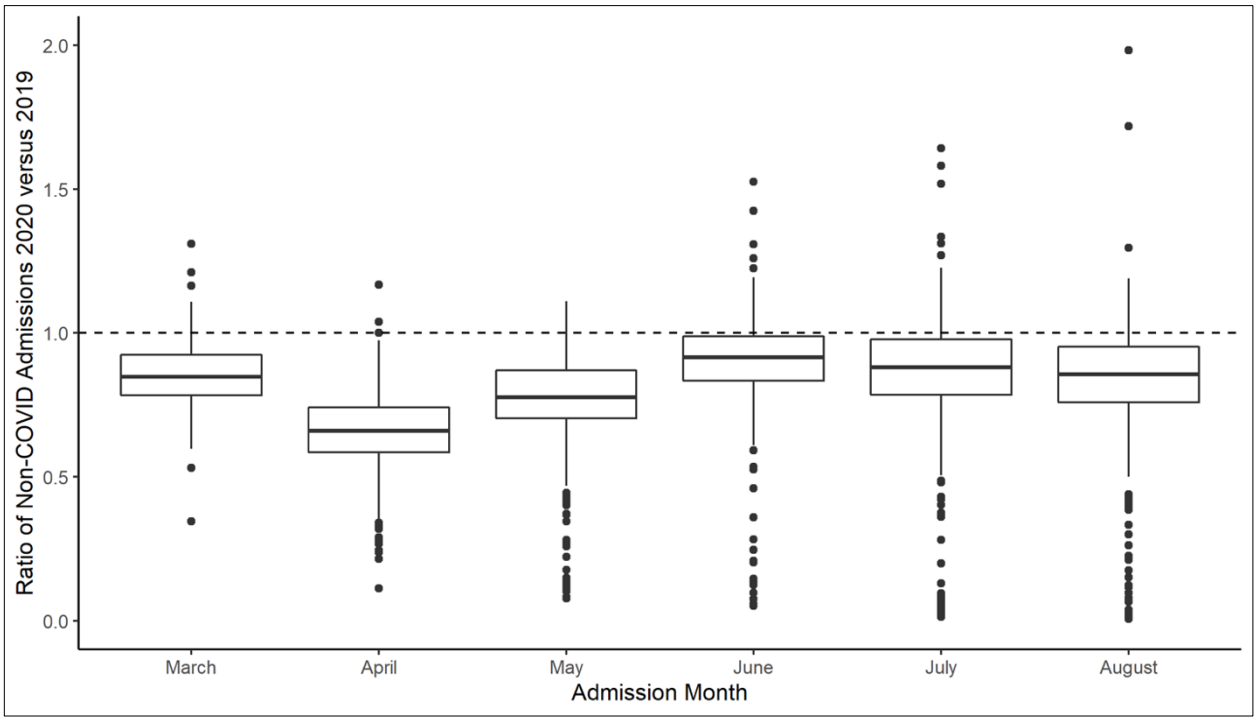
ICU = Intensive Care Unit
NIPPV = Noninvasive Positive-pressure Ventilation

Supplement Figure 6A–B: Distribution of [A] Non-COVID Index Strata and [b] 2019:2020 Ratio of Non-COVID Caseload by Month, 558 U.S. Hospitals, March–August 2020

[A]



[B]



[A] Each horizontal panel represents the monthly proportional distribution of hospitals stratified as low (<50% non-COVID index; blue bars), medium (50-75% of non-COVID index; yellow bars) and high (75%+ non-COVID index values; red bars) non-COVID index. Non-COVID index was calculated using the same formula as surge index except relacing COVID-19 with non-COVID counts. The numbers above each color coded bar represents the monthly count of hospitals in that stratum of non-COVID index. [A] Horizontal solid lines represent medians, upper and lower margins of boxes represent interquartile range, vertical lines represent 95% confidence intervals and dots represent outlier estimates

Supplement Table 7: Sensitivity analyses of Categorical Surge Index, 558 U.S. Hospitals, March–August 2020

		aOR	Lower 95% Confidence Interval	Upper 95% Confidence Interval	p-value
Model	**Surge Index**				
Using Elixhauser Score(6) (in lieu of CDC-defined high risk comorbidities)	50%-75% vs. <50%	1.1133	1.0082	1.2293	0.0339
	75%-90% vs. <50%	1.238	1.1136	1.3763	<0.0001
	90%-95% vs. <50%	1.4291	1.272	1.6055	<0.0001
	95%-999% vs. <50%	1.5901	1.4073	1.7966	<0.0001
	99%+ vs. <50%	2.0096	1.6894	2.3905	<0.0001
Using Deciles above median Surge Index (in lieu of shrinking percentile categories)	50%-60% vs. <50%	1.0477	0.9332	1.1762	0.4304
	60%-70% vs. <50%	1.077	0.9685	1.1978	0.171
	70%-80% vs. <50%	1.137	1.0269	1.2589	0.0135
	80%-90% vs. <50%	1.2757	1.1552	1.4087	<0.0001
	90%+ vs. <50%	1.507	1.3546	1.6766	<0.0001
Using Unweighted Surge Index (in lieu of assigning a weight of 2 to ICU/NIPPV and 5 to mechanically ventilated encounters)	50%-75% vs. <50%	1.0819	0.9948	1.1767	0.066
	75%-90% vs. <50%	1.2764	1.1586	1.4062	<0.0001
	90%-95% vs. <50%	1.3502	1.2047	1.5131	<0.0001
	95%-99% vs. <50%	1.6355	1.4363	1.8622	<0.0001
	99%+ vs. <50%	2.0024	1.6997	2.3591	<0.0001
Excluding COVID-19-targeted Medications as secondary covariates	50%-75% vs. <50%	1.1509	1.0444	1.2683	0.0046
	75%-90% vs. <50%	1.3231	1.1954	1.4645	<0.0001
	90%-95% vs. <50%	1.5347	1.3733	1.7152	<0.0001
	95%-99% vs. <50%	1.7358	1.5496	1.9444	<0.0001
	99%+ vs. <50%	2.2734	1.9394	2.6648	<0.0001
Imputing all discharges to hospice as alive (in lieu of deceased)	50%-75% vs. <50%	1.0799	0.9746	1.1965	0.1419
	75%-90% vs. <50%	1.2031	1.0782	1.3424	0.0009
	90%-95% vs. <50%	1.3662	1.2124	1.5395	<0.0001
	95%-99% vs. <50%	1.5023	1.3194	1.7105	<0.0001
	99%+ vs. <50%	2.0153	1.6752	2.4246	<0.0001
Imputing all discharges who received tracheostomy and discharged alive as deceased	50%-75% vs. <50%	1.1315	1.0249	1.2492	0.0144
	75%-90% vs. <50%	1.2445	1.1205	1.3822	<0.0001
	90%-95% vs. <50%	1.4171	1.2631	1.5898	<0.0001
	95%-99% vs. <50%	1.5564	1.378	1.7579	<0.0001
	99%+ vs. <50%	1.965	1.6633	2.3214	<0.0001
Imputing all discharges to acute hospitals as deceased	50%-75% vs. <50%	1.0443	0.9481	1.1502	0.3791
	75%-90% vs. <50%	1.0794	0.9754	1.1945	0.1393
	90%-95% vs. <50%	1.2107	1.0808	1.3563	0.001
	95%-99% vs. <50%	1.3507	1.2037	1.5156	<0.0001
	99%+ vs. <50%	1.8039	1.5285	2.1289	<0.0001

CDC = Centers for Disease Control
ICU = Intensive Care Unit
NIPPV = Noninvasive Positive-pressure Ventilation
COVID-19 = Coronavirus Disease 2019

Supplement Table 8: Sensitivity analyses of Continuous (Log) Surge Index, 558 U.S. Hospitals, March–August 2020

	Not Adjusted for Hospital Mean log Surge Index				Adjusted for Hospital Mean Log Surge Index*			
Model	**aOR**	**Lower 95% CI**	**Upper 95% CI**	**p-value**	**aOR**	**Lower 95% CI**	**Upper 95% CI**	**p-value**
Primary analysis (continuous exposure variable)								
Log transformed Surge Index	1.2221	1.1747	1.2714	<0.0001	1.2245	1.1748	1.2763	<0.0001
Sensitivity analyses								
Using Elixhauser Score(6) (in lieu of CDC-defined high risk comorbidities)	1.2217	1.1742	1.2711	<0.0001	1.2243	1.1746	1.2761	<0.0001
Using Unweighted Surge Index (in lieu of assigning a weight of 2 to ICU/NIPPV and 5 to mechanically ventilated encounters)	1.1981	1.1508	1.2474	<0.0001	1.1972	1.480	1.2485	<0.0001
Excluding COVID-19-targeted Medications as secondary covariates	1.2681	1.2233	1.3145	<0.0001	1.2739	1.2270	1.3227	<0.0001
Imputing all discharges to hospice as alive (in lieu of deceased)	1.2242	1.1724	1.2783	<0.0001	1.2315	1.1764	1.2891	<0.0001
Imputing all discharges who received tracheostomy and discharged alive as deceased	1.2076	1.1614	1.2556	<0.0001	1.2059	1.1574	1.2563	<0.0001
Imputing all discharges to acute hospitals as deceased	1.1822	1.1337	1.2327	<0.0001	1.2024	1.1513	1.2556	<0.0001

*based on Begg et al.[7] to adjust for clustering at the hospital level

References

1. Kadri SS, Gundrum J, Warner S, et al. Uptake and accuracy of the diagnosis code for COVID-19 among US hospitalizations. JAMA. 2020;324:2553-4. [PMID: 33351033] doi:10.1001/jama.2020.20323
2. Centers for Medicare & Medicaid Services. The Centers for Medicare & Medicaid Services (CMS) Fact Sheet for State and Local Governments: CMS Programs & Payment for Care in Hospital Alternate Care Sites. 26 May 2020.
3. Diggle P, Heagerty P, Liang K, et al. Analysis of Longitudinal Data. Second Edition. Oxford Univ Pr; 2002:140.
4. Kadri SS, Demirkale CY, Sun J, et al. Real-world inpatient use of medications repurposed for coronavirus disease 2019 in United States hospitals, March–May 2020. Open Forum Infect Dis. 2021;8:ofaa616. [PMID: 33556157] doi:10.1093/ofid/ofaa616
5. Courtright KR, Halpern SD, Bayes B, et al. Adaptation of the Acute Organ Failure Score for use in a Medicare population. Crit Care Med. 2017;45:1863-70. [PMID: 28777196] doi:10.1097/CCM.0000000000002651
6. Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Med Care. 2005;43:1130-9. [PMID: 16224307]
7. Begg MD, Parides MK. Separation of individual-level and cluster-level covariate effects in regression analysis of correlated data. Stat Med. 2003;22:2591-602. [PMID: 12898546]