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Surge in Incidence and Coronavirus Disease 2019 Hospital Risk of Death, United States, September 2020 to March 2021

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Background. Studies of the early months of the coronavirus disease 2019 (COVID-19) pandemic indicate that patient outcomes may be adversely affected by surges. However, the impact on in-hospital mortality during the largest surge to date, September 2020–March 2021, has not been studied. This study aimed to determine whether in-hospital mortality was impacted by the community surge of COVID-19.

Methods. This is a retrospective cohort study of 416 962 adult COVID-19 patients admitted immediately before or during the surge at 229 US academic and 432 community hospitals in the Vizient Clinical Database. The odds ratios (ORs) of death among hospitalized patients during each phase of the surge was compared with the corresponding odds before the surge and adjusted for demographic, comorbidity, hospital characteristic, length of stay, and complication variables.

Results. The unadjusted proportion of deaths among discharged patients was 9% in both the presurge and rising surge stages but rose to 12% during both the peak and declining surge intervals. With the presurge phase defined as the referent, the risk-adjusted ORs (aORs) for the surge periods were rising, 1.14 (1.10–1.19), peak 1.37 (1.32–1.43), and declining, 1.30 (1.25–1.35). The surge rise in-hospital mortality was present in 7 of 9 geographic divisions and greater for community hospitals than for academic centers.

Conclusions. These data support public policies aimed at containing pandemic surges and supporting healthcare delivery during surges.

Keywords. COVID-19; hospitals; mortality; pandemics; surge capacity.

In 2007, the US Centers for Disease Control and Prevention warned that a severe pandemic could overwhelm the nation's healthcare capacity and that nonpharmacologic interventions could "delay and flatten the epidemic peak" [1]. The coronavirus disease 2019 (COVID-19) pandemic has put this to the test [2].

As the COVID-19 pandemic has progressed, distinct surges of US hospitalizations and in-hospital deaths have occurred [3]. Despite recurrent spikes in caseloads, the overall proportion of hospitalized patients who died has trended downward in the first year of the pandemic [4–7], although prior studies have shown that hospitalized COVID-19 patients have higher reported case fatality during surge periods [8–12].

We studied a large national sample of hospitalized patients from all divisions of the United States, focusing on the large surge period from September 2020 to March 2021. Our objective was to determine whether the risk of death among hospitalized COVID-19 patients was higher during surge. Our secondary objectives were to determine whether known prognostic factors accounted for any observed increase in fatality and whether mortality excess varied by geographic division or hospital type.

METHODS

This investigation utilizes the Vizient Clinical Data Base, a repository of clinical, administrative, and financial information on inpatient admissions and outpatient visits. Patient-specific discharge data are extracted from hospital billing systems from over 800 US academic, teaching, and community hospitals representing from over 10 million inpatient admissions and 150 million outpatient visits per year. Participating hospitals are subdivided into 2 categories. Academic hospitals, includes university medical centers, cancer, and children's

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hospitals, and teaching facilities with a case-mix index of 1.25 or greater. Community hospitals includes nonacademic and smaller local hospitals. The present study includes 661 total hospitals: 229 academic and 432 community.

The dataset, extracted on June 14, 2021, for hospital dispositions through March 2021, includes demographic characteristics, comorbidities, treatments, complications, lengths of stay, and outcomes. Complications and vital events after discharge were not analyzed. Vizient granted permission for the analysis and provided deidentified source data on individual hospitals and patients. The protocol was reviewed by the UT Health Institutional Review Board and found to be of minimal risk due to a lack of direct patient contact. A waiver of informed consent and exemption were granted. This study adhered to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement guidelines [13].

The study population is segmented into 9 specific geographic divisions of the United States using 2010 criteria established by the US Census Bureau (Supplementary Figure *A*) [14]. Hospitalized adults (aged ≥18 years) with a diagnosis of COVID-19 were eligible for inclusion if final disposition (death or discharge alive) occurred in the presurge, rising surge, peak surge, or declining surge time periods. Since the timing of surges between September 2020 and March 2021 varied across geographic divisions of the United States, the definition of these 4 periods was division-specific (Supplementary Figure *B*) and derived from population-based incident case. Incident cases were retrieved through the New York Times Open Source COVID-19 Data site [15]. Presurge was defined as the baseline timespan ending with an initial rise in division-specific incident case numbers. Rising surge corresponded to the positive slope phase. Peak surge was when incident case counts were at or near a maximum. Declining surge corresponded to the subsequent period of negative slope. The resulting shapes of the surge varied considerably across geographic divisions, with broad and flat elevations in East South Central, Mountain, and New England, and steep ascents and declines in the East North Central, South Atlantic, and Middle Atlantic (Supplementary Figure *C*).

Patients were identified using the COVID-19-specific diagnosis code (U07.1) from the *International Classification of Diseases, 10th Revision, Clinical Modification* (ICD-10-CM) effective April 1, 2020 [16]. Comparing severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) polymerase chain reaction test results in a large national database, use of this diagnosis code showed a sensitivity of 98%, specificity of 99%, positive predictive value of 92%, and negative predictive value of approximately 100% [17].

The independent variable of primary interest was the level of surge reflected by the division-specific counts of incident cases. The presurge interval was the reference period, and 3 binary categorical variables were constructed to represent the rising, peak, and declining surge periods. The dependent variable was the proportion of final discharges that were deceased (discharged alive = 0, in-hospital death = 1). Covariables included demographic characteristics, comorbidities, hospital type (academic = 0, community = 1), duration of hospital stay, and inpatient complications. Demographic variables in the Vizient data were assigned in the dataset based on data from each contributing hospital following hospital-specific rules and procedures. These data included the following: age (coded in ordinal categories of 18–29 years [referent], 30–39 years, 40–49 years, 50–64 years, 65–79 years, 80+ years), sex (coded as female = 0, male = 1), race-ethnicity (coded as binary categorical variables for White Non-Hispanic [referent], Asian, Black Non-Hispanic, Hispanic, Other, and unavailable), health insurance status (coded as binary categorical variables for private [referent], Medicaid, Medicare, other public/self-pay/uninsured, other, and unknown), and census geographic division (coded as binary indicator variables for Middle Atlantic [referent], East North Central, East South Central, Mountain, New England, Pacific, South Atlantic, West North Central, and West South Central).

Comorbidities were from Agency for Healthcare Research and Quality (AHRQ)/Elixhauser chronic comorbid conditions ICD-10-CM codes developed as part of the Healthcare Cost and Utilization Project [18]. Comorbidities (coded as 0 = absent, 1 = present) included diabetes with and without complications, hypertension, chronic peptic ulcer disease, chronic pulmonary disease, congestive heart failure, valvular disease, rheumatoid arthritis/collagen vascular disease, pulmonary circulation disorders, peripheral vascular disorders, coagulation deficiencies, blood loss anemia, deficiency anemias, paralysis, other neurologic disorders, renal failure, fluid and electrolyte disorders, lymphoma, solid tumor without metastasis, human immunodeficiency virus/acquired immune deficiency syndrome, hypothyroidism, liver disease, obesity, weight loss, depression, psychoses, alcohol abuse, and drug abuse. Complications during hospitalization (coded as absent = 0, present = 1) included stroke, aspiration pneumonia, gastrointestinal hemorrhage, acute myocardial infarction, and *Clostridium difficile* infection.

The univariate distributions of the independent variables were examined within each surge stage. The unadjusted proportion of deaths among hospital discharges was explored across surge stage and geographic division. The surge stages were compared using χ^2 test for categorical and Kruskal-Wallis test for continuous variables. To account for intracluster correlation within a given hospital facility or a particular division, mathematical modeling was performed with a generalized linear mixed-effects analysis, containing both fixed and random effects [19]. A random effect was included to account for possible within-hospital clustering. An unadjusted logistic regression model was constructed in a series of 3 binary

indicator variables (referent = presurge) as the only independent variables and vital status at discharge as the dependent variable. A stepwise forward approach was used to construct the adjusted model for surge stage including demographic, comorbidity, hospital characteristic, length of stay, and complication independent variables. To assess whether any observed surge effect was modified by geographic division or hospital type, separate fully adjusted models were constructed by the level of these covariables.

The predicted outcome from the fully adjusted model was calculated for each surge stage by treating everyone in the dataset to have belonged to pre-, rising, peak, and declining surge periods. Predicted hospital deaths in the community were then calculated by multiplying the observed COVID-19 cases reported by *The New York Times* [15] with the infection hospitalization rate and the average of the predicted probabilities from the model.

Predicted hospital deaths
= (Observed COVID-19 cases in community)
× (infection hospitalization rate)
× (average of the predicted death probabilities from the model)

Infection hospitalization rate was estimated using data on hospitalizations and cases in The COVID Tracking Project [20]. Excess hospital deaths during each surge stage were calculated by multiplying the observed phase-specific COVID-19 cases in community with the infection hospitalization rate and difference of the average of the predicted probabilities from the model for presurge and relevant surge stage.

Excess hospital deaths
= (Observed COVID-19 cases in community during surge)
× (infection hospitalization rate during surge)
× (average of the predicted probabilities
from the model during surge
− average of the predicted probabilities from the
model during pre-surge).

RESULTS

A total of 423 469 COVID-19 patients were discharged during the division-specific surge phases. A total of 6476 (1.5%) were under the age of 18 years and were excluded from further analysis and 31 patients (0.01%), missing information on age or sex were excluded, leaving a study population of 416 962 persons.

The distribution of demographic characteristics, comorbidities, hospital type, and inpatient complications is shown in Table 1. Given the large numbers of observations in the 4 time periods, small differences in percentages were determined to be statistically significant. The age distribution of patients discharged during presurge was younger than during the surge, with almost twice the percentage of the youngest and approximately one third less of the oldest adults compared with the peak. As expected, this resulted in a larger proportion of Medicare patients discharged during the surge. The percentages of White non-Hispanic patients were lower, and the percentages of Black non-Hispanic and Hispanic patients higher during the presurge period. The presurge period included higher proportions of patients in East and West North Central, West South Central, and South Atlantic and smaller proportions in Middle Atlantic, Mountain, and Pacific than during the peak. During the presurge period, a slightly higher percentage of discharges occurred in academic medical centers.

Each of the 5 in-hospital complications was a relatively rare event with no discernible differences before and during the surge. Among the 27 comorbidities examined, only a few appeared to have prevalences that varied by time period by more than 1%. Hypertension was more common among patients discharged during the surge, as was renal failure and fluid and electrolyte disorders.

In Table 2, total discharges and in-hospital deaths, with proportion of in-hospital death, are shown by surge phase and geographic division. The total number of in-hospital deaths was 46 614, for a proportion of in-hospital death of 11.2%. The proportion of in-hospital deaths rose from a baseline of 9% presurge to 10% during the rising surge and 12% during both peak and declining surge phases. The East South Central and Pacific divisions had comparatively high mortality proportions across all surge phases, whereas New England experienced relatively low proportions.

The unadjusted associations between phase of surge and risk of death showed a minimally elevated odds ratio of 1.04 (1.00–1.08) during the rising surge that grew appreciably during the peak at 1.33 (1.28–1.38) and declining surge at 1.39 (1.35–1.44) (Supplementary Table *A*). Separate univariate analyses were performed to examine the relationship of other factors with the risk of death (Supplementary Table *A*). Age was a powerful predictor of death, with patients 80+ having a 20-fold increased risk compared with those 18–29 years of age, and Medicare beneficiaries similarly had a comparatively high odds of death. Males experienced an elevated risk of death, whereas non-Hispanic Blacks and Hispanics had reduced risks. Patients in the East South Central and Pacific had an elevated risk, whereas patients in community hospitals had a lower likelihood of death. Complications during hospitalization were potent predictors of death, with the greatest risk among those with acute myocardial infarction, followed by stroke, gastrointestinal hemorrhage, and aspiration pneumonia. Individual comorbidities strongly linked to death were coagulation deficiencies, fluid and electrolyte disorders, a history of weight loss, congestive heart failure, renal failure, hypertension, metastatic cancer, peripheral vascular disease, deficiency anemias, and diabetes with complications.

The association between surge phase and risk of mortality adjusted for all demographic characteristics, comorbidities,

Table 1. Demographics, Clinical Characteristics, and Comorbidities of Patients by Surge Phase

Characteristics	Presurge (*N* = 55 972) *N* (%)	Rising Surge (*N* = 94 060) *N* (%)	Peak Surge (*N* = 120 653) *N* (%)	Declining Surge (*N* = 146 277) *N* (%)	*P* Value
Age Group					
18–29	5019 (8.97)	5285 (5.62)	5673 (4.70)	7217 (4.93)	<.001
30–39	5414 (9.67)	6968 (7.41)	7725 (6.40)	9289 (6.35)	
40–49	6290 (11.24)	9643 (10.25)	10 564 (8.76)	12 885 (8.81)	
50–64	15 094 (26.97)	25 368 (26.97)	31 546 (26.15)	38 747 (26.49)	
65–79	15 893 (28.39)	29 879 (31.77)	40 342 (33.44)	49 165 (33.61)	
80+	8262 (14.76)	16 917 (17.99)	24 803 (20.56)	28 974 (19.81)	
Sex					
Female	27 829 (49.72)	44 656 (47.48)	56 819 (47.09)	68 776 (47.02)	<.001
Male	28 143 (50.28)	49 404 (52.52)	63 834 (52.91)	77 501 (52.98)	
Race-Ethnicity					
White	25 622 (45.78)	51 831 (55.10)	67 068 (55.59)	81 745 (55.88)	<.001
Asian	1496 (2.67)	2778 (2.95)	4623 (3.83)	5124 (3.50)	
Black	13 896 (24.83)	17 553 (18.66)	19 167 (15.89)	28 559 (19.52)	
Hispanic	10 878 (19.43)	15 901 (16.91)	21 277 (17.63)	21 562 (14.74)	
Other	2968 (5.30)	4535 (4.82)	6261 (5.19)	6755 (4.62)	
Unavailable	1112 (1.99)	1462 (1.55)	2257 (1.87)	2532 (1.73)	
Primary Payer					
Private insurance	13 896 (24.83)	25 135 (26.72)	29 277 (24.27)	35 064 (23.97)	<.001
Medicaid	11 310 (20.21)	13 728 (14.59)	18 383 (15.24)	20 876 (14.27)	
Medicare	25 705 (45.92)	47 822 (50.84)	65 838 (54.57)	80 337 (54.92)	
Public other/self-pay/uninsured	2728 (4.87)	3718 (3.95)	3562 (2.95)	5276 (3.61)	
Other	1876 (3.35)	3083 (3.28)	2974 (2.46)	3983 (2.72)	
Unknown	399 (0.71)	536 (0.57)	562 (0.47)	646 (0.44)	
Census Division					
Middle Atlantic	10 648 (19.02)	15 106 (16.06)	28 133 (23.32)	23 218 (15.87)	<.001
East North Central	12 319 (22.01)	15 437 (16.41)	20 968 (17.38)	33 344 (22.80)	
East South Central	2828 (5.05)	3004 (3.19)	3723 (3.09)	3248 (2.22)	
Mountain	1877 (3.35)	5826 (6.19)	14 134 (11.71)	6894 (4.71)	
New England	2911 (5.20)	6900 (7.34)	9015 (7.47)	6887 (4.71)	
Pacific	2734 (4.88)	5095 (5.42)	12 715 (10.54)	8749 (5.98)	
South Atlantic	10 857 (19.40)	22 320 (23.73)	15 789 (13.09)	25 304 (17.30)	
West North Central	5835 (10.42)	8792 (9.35)	7903 (6.55)	21 623 (14.78)	
West South Central	5963 (10.65)	11 580 (12.31)	8273 (6.86)	17 010 (11.63)	
Length of Stay					
Days (median, IQR)	6 (3–11)	5 (3–9)	5 (3–10)	5 (3–8)	<.001
Patients					
Academic hospitals	35 914 (64.16)	55 661 (59.18)	73 404 (60.84)	89 772 (61.37)	<.001
Community hospitals	20 058 (35.84)	38 399 (40.82)	47 249 (39.16)	56 505 (38.63)	
Complications					
Stroke (in hospital)	530 (0.95)	550 (0.58)	776 (0.64)	1352 (0.92)	<.0001
Aspiration pneumonia	685 (1.22)	699 (0.74)	1071 (0.89)	1860 (1.27)	<.0001
GI hemorrhage	663 (1.18)	587 (0.62)	956 (0.79)	1696 (1.16)	<.0001
Acute MI (in hospital)	380 (0.68)	545 (0.58)	781 (0.65)	1128 (0.77)	<.0001
Clostridium difficile (hospital acquired)	186 (0.33)	185 (0.2)	264 (0.22)	458 (0.31)	<.0001
Comorbidities					
Diabetes (with complications)	14 081 (25.16)	23 351 (24.83)	31 530 (26.13)	41 134 (28.12)	<.0001
Diabetes (without complications)	6432 (11.49)	11 127 (11.83)	14 717 (12.2)	15 940 (10.9)	<.0001
Hypertension	32 674 (58.38)	58 733 (62.44)	77 456 (64.2)	94 911 (64.88)	<.0001
Chronic pulmonary disease	11 917 (21.29)	21 070 (22.4)	27 576 (22.86)	34 330 (23.47)	<.0001
Congestive heart failure	8623 (15.41)	14 615 (15.54)	19 909 (16.5)	26 230 (17.93)	<.0001
Valvular disease	2587 (4.62)	4643 (4.94)	6311 (5.23)	8182 (5.59)	<.0001
Rheumatoid arthritis/Collagen vascular disease	1811 (3.24)	3160 (3.36)	4138 (3.43)	5282 (3.61)	<.0001
Pulmonary circulation disorders	1321 (2.36)	2415 (2.57)	3581 (2.97)	5388 (3.68)	<.0001
Peripheral vascular disorders	2361 (4.22)	3770 (4.01)	5497 (4.56)	7413 (5.07)	<.0001

Table 1. Continued

Characteristics	Presurge (*N* = 55 972) *N* (%)	Rising Surge (*N* = 94 060) *N* (%)	Peak Surge (*N* = 120 653) *N* (%)	Declining Surge (*N* = 146 277) *N* (%)	*P* Value
Coagulation deficiency	5765 (10.3)	9135 (9.71)	11 878 (9.84)	15 776 (10.79)	<.0001
Deficiency anemias	12 446 (22.24)	17 100 (18.18)	23 575 (19.54)	32 317 (22.09)	<.0001
Paralysis	2284 (4.08)	2775 (2.95)	3989 (3.31)	5412 (3.7)	<.0001
Other neurological disorders	5757 (10.29)	9053 (9.62)	12 171 (10.09)	15 857 (10.84)	<.0001
Renal failure	10 938 (19.54)	18 916 (20.11)	26 697 (22.13)	34 221 (23.39)	<.0001
Fluid electro disorders	23 255 (41.55)	38 915 (41.37)	53 076 (43.99)	65 749 (44.95)	<.0001
Lymphoma	502 (0.9)	873 (0.93)	1268 (1.05)	1889 (1.29)	<.0001
Metastatic cancer	848 (1.52)	1301 (1.38)	1803 (1.49)	2412 (1.65)	<.0001
Solid tumor without metastasis	974 (1.74)	1738 (1.85)	2361 (1.96)	3008 (2.06)	<.0001
HIV/AIDS	66 (0.12)	59 (0.06)	80 (0.07)	137 (0.09)	.0003
Hypothyroidism	6969 (12.45)	13 123 (13.95)	17 341 (14.37)	21 062 (14.4)	<.0001
Liver disease	3133 (5.6)	4817 (5.12)	6299 (5.22)	8499 (5.81)	<.0001
Obesity	16 315 (29.15)	28 590 (30.4)	34 936 (28.96)	44 061 (30.12)	<.0001
Weight loss	4812 (8.6)	6245 (6.64)	9033 (7.49)	13 728 (9.38)	<.0001
Depression	7233 (12.92)	12 127 (12.89)	15 976 (13.24)	20 580 (14.07)	<.0001
Psychoses	2738 (4.89)	3537 (3.76)	5092 (4.22)	6978 (4.77)	<.0001
Alcohol abuse	1729 (3.09)	2211 (2.35)	3093 (2.56)	4317 (2.95)	<.0001
Drug abuse	1503 (2.69)	1846 (1.96)	2647 (2.19)	3833 (2.62)	<.0001

Abbreviations: AIDS, acquired immune deficiency syndrome; GI, gastrointestinal; HIV, human immunodeficiency virus; IQR, interquartile range; MI, myocardial infarction.

Table 2. Distribution of Hospital Discharges and Unadjusted Deaths and Unadjusted Proportion of In-Hospital Deaths by US Census Geographic Division and Surge Phase

	Presurge			Rising Surge			Peak Surge			Declining Surge		
Census Division	Cases	Deaths	% Deaths	Cases	Deaths	% Deaths	Cases	Deaths	% Deaths	Cases	Deaths	% Deaths
East North Central	12 319	1039	8.43	15 437	1376	8.91	20 968	2173	10.36	33 344	3841	11.52
East South Central	2828	399	14.11	3004	412	13.72	3723	584	15.69	3248	504	15.52
Middle Atlantic	10 648	828	7.78	15 106	1246	8.25	28 133	3226	11.47	23 218	2791	12.02
Mountain	1877	158	8.42	5826	460	7.90	14 134	1671	11.82	6894	885	12.84
New England	2911	183	6.29	6900	517	7.49	9015	905	10.04	6887	692	10.05
Pacific	2734	314	11.49	5095	504	9.89	12 715	2249	17.69	8749	1709	19.53
South Atlantic	10 857	1131	10.42	22 320	2343	10.50	15 789	1832	11.60	25 304	2841	11.23
West North Central	5835	549	9.41	8792	984	11.19	7903	1006	12.73	21 623	2755	12.74
West South Central	5963	556	9.32	11 580	1099	9.49	8273	829	10.02	17 010	2023	11.89
Overall	55 972	5157	9.21%	94 060	8941	9.51%	120 653	14 475	12.0%	146 277	18 041	12.3%

hospital type, and in-patient complications showed slight increases in association with rising surge at 1.14 (1.10–1.19), peak surge at 1.37 (1.32–1.43), and a minor reduction with declining surge at 1.30 (1.25–1.35) (Supplementary Table *A*).

The adjusted associations between surge phase and risk of in-hospital death are depicted in Figure 1. Surge impact was seen in all divisions, with the highest risk during peak surge, followed by declining then rising surge intervals. The magnitude of surge influence varied across geographic divisions. The strongest impact was seen in Middle Atlantic and Pacific, followed by New England and Mountain. The influence of the surge was least apparent in East South Central and South Atlantic.

The adjusted associations between surge phase and risk of in-hospital death showed a similar pattern in both academic and community hospitals. There was a modest increase in rising surge, reaching a maximum during peak surge, and falling slightly in declining surge. Overall, associations were slightly stronger in community hospitals than in academic hospitals (Supplementary Table *A*).

In the fully adjusted model, including demographic, geographic, and hospital characteristics, as well as 27 comorbidities and 5 complications, the strongest predictor of in-hospital death risk was age, with a gradient of increasing risk with advancing age culminating in an odds ratio of 10.72 (9.48–12.13) for those 80 years and older compared with those

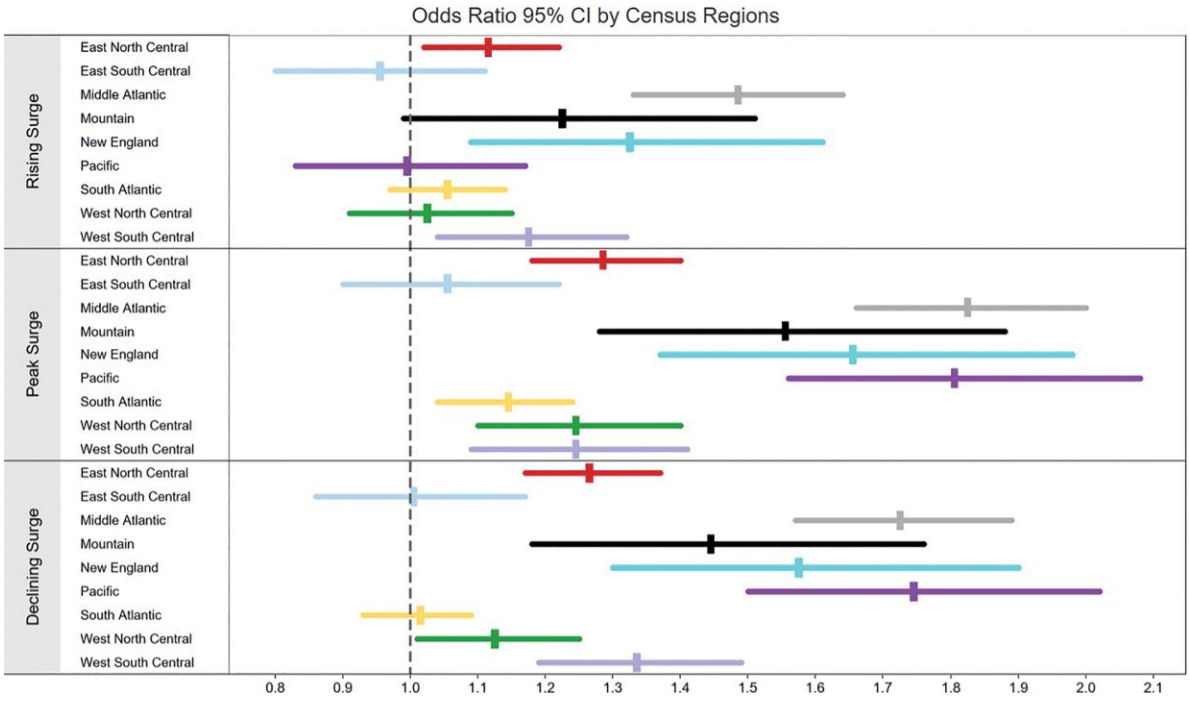

Figure 1. Adjusted odds ratios between surge phases and risk of in-hospital death, by Census division. CI, confidence interval.

18–29 years. The next strongest predictors were the following in-hospital complications: myocardial infarction at 5.45 (5.01–5.93), stroke at 4.34 (4.01–4.70), gastrointestinal hemorrhage at 3.34 (3.11–3.59), and aspiration pneumonia at 2.06 (1.92–2.22). Among the comorbidities, the strongest adjusted associations with in-hospital death risk were observed for coagulation deficiency at 1.91 (1.86–1.97), fluid and electrolyte disorders at 1.86 (1.82–1.90), metastatic cancer at 1.64 (1.53–1.76), and pulmonary circulation disorders 1.51 (1.43–1.59). Other noteworthy adjusted associations with risk of death included male sex at 1.36 (1.33–1.39), Hispanic ethnicity at 1.29 (1.20–1.38), Asian race at 1.21 (1.14–1.29), other public/self-pay/uninsured at 1.43 (1.33–1.54), East South Central division at 1.80 (1.35–2.38), and Pacific division at 1.50 (1.24–1.82).

The excess hospital deaths during surge phases are shown in Table 3. A total of 20 719 477 COVID-19 cases were observed in the community during the surge phases. Based on the model, the total excess hospital deaths during surge phases compared to presurge was 16 925 (9379–24 470).

DISCUSSION

In this study, we observed an association between surge in community COVID-19 cases and risk of death among hospital discharges with COVID-19 between September 2020 and March 2021. This finding is consistent with early pandemic reports from April [6], May [9, 10, 21], and June [5] 2020 covering the initial surge and August [11, 12], which included the first and second surges. None of these reports extended into the fall and winter 2020–2021 surge when we had more pharmacologic treatment options and experience in hospital capacity management.

Previous studies were limited geographically [9, 10], or to a specialized hospital type [11]. In this study, all US geographic divisions were included, as were both academic and community hospitals. The earlier reports covered the 2 smaller initial surges, and the numbers of patients were modest: 620 [10], 2233 [9], 8516 [11], 14 226 [6], 38 517 [5], and 144 116 [12]. The present study, with 416 962 subjects, allowed calculation of more precise estimates, adjusting for dozens of covariables, and permitted a thorough evaluation of subgroups by geography and hospital type.

We observed an increasing likelihood of in-hospital death during the early phases of the surge, reaching a maximum during surge peak, with partial reduction as surge declined. Increased risk of in-hospital deaths was observed in both academic and community hospitals and occurred in 7 of 9 geographic divisions. The similarity of the pattern across settings suggests shared factors contributed to elevated risk.

One possible explanation is that limited bed capacity shifted admitting preference to the most severely ill. In our data, patients admitted during the surge had slightly higher rates of hypertension, fluid and electrolyte disorders, and renal failure. Nevertheless, adjusting for differences in the prevalence of

Table 3. Model-Based Prediction of Overall Excess COVID-19 Hospital Deaths Due to Surge Phases Based on Total Observed Community Cases

Phase	Observed COVID-19 Cases	COVID-19 Hospitalization Rate	Predicted Probability of Hospital Deaths	Predicted Hospital Deaths	Excess Hospital Deaths Compared to Presurge (Lower Limit–Upper Limit)
Presurge	2 653 978	6.35%	9.34%	15 749	…
Rising Surge	6 576 665	4.30%	10.34%	29 217	2817 (470–5164)
Peak surge	7 676 565	4.16%	11.89%	37 968	8144 (5391–10 898)
Declining Surge	6 466 247	4.49%	11.39%	33 076	5963 (3518–8408)

Abbreviations: COVID-19, coronavirus disease 2019.

these and other comorbidities did not diminish the surge effect on mortality risk. Therefore, it does not appear that the observed trend was attributable to more severely ill patients.

Another possible explanation is that during the surge, hospitals were forced to make decisions adversely affecting patient care. Hospitals that adapted to the early pandemic surges expanded ward and intensive care unit capacity, brought in new providers, changed provider responsibilities, and raised patient-to-provider ratios [22]. These measures arguably saved lives; nevertheless, health system strain and excessive workloads could have resulted in a higher percentage of adverse outcomes. In one study, of 30 different admitting diagnoses, 16 resulted in statistically significant elevated in-hospital mortality during the first 10 months of the pandemic [23]. In another, an increase in catheter-associated urinary tract and central line infections [10] possibly reflects decreased quality of care in high-stress environments beyond just COVID-19 patients.

The Vizient dataset used in this study deidentified and grouped individual hospitals by division. This provided a large, high-quality data set, but not direct measures of hospital or provider stress, such as bed capacity, census, staffing, patient-provider ratios, available equipment, or supply chain restraints. Standard indicators of in-hospital complications, such as stroke, acute myocardial infarction, aspiration pneumonia, gastrointestinal bleeding, and *C difficile* infection, were not more common during the height of the surge. Adjustment for them had no apparent effect on the association between surge and hospital mortality. Traditionally measurable adverse events, however, may not reflect a primary concern in a respiratory illness like COVID-19, in which critical care teams are being overwhelmed and unable to concurrently manage an overload of ventilated and highly medicated patients.

The implications for health policy are profound. Of critical importance are pandemic containment strategies to prevent or moderate surges. Even variants, such as Omicron [24, 25], that exhibit a lower effective severity of illness than prior variants, risk overwhelming hospitals with higher transmissibility and resultant high overall case numbers. Additional strategies are needed to move providers more effectively to areas of greatest need during surges and support a reserve workforce. Equally critical is standardization of surge plan strategies, such as defined by the California Hospital Association [26]. Surge plans should be regionally coordinated to increase capacity and capabilities among acute care institutions and to decrease significant variation in patient burden. Particular focus should be on vulnerable populations with disparities in underlying health and socioeconomic determinants.

There are several potential limitations of this study, including reliance on administrative data, which may lack the completeness and accuracy of information gathered for research [27]. Discharge status and week of discharge are unlikely to be misclassified, although covariables, such as comorbidities and hospital complications, might be classified incorrectly or omitted [28]. Second, included hospitals participate in a voluntary consortium so results may not be generalizable across hospitals. One third of the hospitals were academic medical centers, and admissions to these facilities may be skewed to more critically ill patients [29]. The fact that the adjusted rise of in-hospital mortality was greater in community hospitals than in academic centers argues against a selection bias accounting for the observed association. Finally, although the effects of many potential determinants of in-hospital death were adjusted in these analyses, we acknowledge that we did not have access to clinical data for further assessing potential severity of illness scores (eg, APACHE or SOFA).

The extent to which these findings apply to subsequent and future surges of COVID-19 will depend on risks of in-hospital mortality from new SARS-CoV-2 variants, the age distribution of hospitalized patients, risk mitigation through vaccination, and progress in therapeutic interventions. Ultimately, the most effective means for addressing the adverse impact of pandemic surges on healthcare services is to prevent surges from occurring, as may be achieved through effective vaccinations [30], masking, social distancing, public health pandemic planning and mitigation, and healthcare policy.

CONCLUSIONS

There was an association between community surge of COVID-19 and in-hospital mortality not attributable to differences in demographic, clinical, or hospital characteristics. These data support healthcare policies aimed at containing

pandemic surges to prevent case overloads for hospitals, public health and public policy efforts to provide supplemental manpower and capacity support to hospitals at risk of surge overload, and standardized hospital surge strategies.

Supplementary Data

Supplementary materials are available at *Open Forum Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

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