PUBLIC HEALTH REPORTS

Public Health Reports
2022, Vol. 137(4) 796–802

DOI: 10.1177/00333549221091781
journals.sagepub.com/home/phr
SAGE

Emergency Department and Intensive Care Unit Overcrowding and Ventilator Shortages in US Hospitals During the COVID-19 Pandemic, 2020-2021

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Abstract

Objective: In 2020, the COVID-19 pandemic overburdened the US health care system because of extended and unprecedented patient surges and supply shortages in hospitals. We investigated the extent to which several US hospitals experienced emergency department (ED) and intensive care unit (ICU) overcrowding and ventilator shortages during the COVID-19 pandemic.

Methods: We analyzed Health Pulse data to assess the extent to which US hospitals reported alerts when experiencing ED overcrowding, ICU overcrowding, and ventilator shortages from March 7, 2020, through April 30, 2021.

Results: Of 625 participating hospitals in 29 states, 393 (63%) reported at least 1 hospital alert during the study period: 246 (63%) reported ED overcrowding, 239 (61%) reported ICU overcrowding, and 48 (12%) reported ventilator shortages. The number of alerts for overcrowding in EDs and ICUs increased as the number of COVID-19 cases surged.

Conclusions: Timely assessment and communication about critical factors such as ED and ICU overcrowding and ventilator shortages during public health emergencies can guide public health response efforts in supporting federal, state, and local public health agencies.

Keywords

public health emergencies, COVID-19 pandemic, emergency department overcrowding, intensive care unit overcrowding, ventilator shortages, real-time data, health care systems, hospital alerts

The COVID-19 pandemic presented unique and unprecedented challenges for the US health care system and changed how health care is delivered. As of January 17, 2022, COVID-19 had accounted for 326 279 424 confirmed cases and 5 536 609 deaths globally[1] and 64 720 612 confirmed cases and 843 718 deaths in the United States.[2] Virtually every country in the world, including the United States, India, Brazil, and the United Kingdom, experienced sudden patient surges during the pandemic that overwhelmed local health care systems with increased demands for acute and urgent care services to treat COVID-19 patients. A massive increase in patient demand led to shortages of key hospital

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resources, including personal protective equipment (PPE) (eg, face shields, N95 respirators, isolation gowns, gloves), adequate hospital staffing, hospital bed capacity, and ventilators in intensive care units (ICUs) and emergency departments (EDs) needed to care for critically ill patients.[3-6]

Evidence supports a well-established association between ED overcrowding and negative impacts on patient safety and adverse medical outcomes, such as treatment delays and increased mortality. ED overcrowding also limits health care systems from providing quality patient care and meeting the urgent care needs of patients in a timely manner because of an inability of staff to adhere to guideline-recommended treatments.[7-10] A retrospective cohort study using data from 187 hospitals found that patients who were admitted during periods of high ED crowding had higher mortality rates (5% [95% CI, 2%-8%] greater odds of inpatient death) compared with similar patients admitted to the same hospital when the ED was less crowded. Patient mortality rates were unchanged after the analysis was adjusted for patient demographic characteristics, comorbidities, and primary discharge diagnosis.[8] During the early phase of the pandemic, reports from China and Italy highlighted the need for health care systems to prepare for meeting massive increases in ICU demand based on the clinical spectrum of disease among patients with SARS-CoV-2 infection resulting in acute respiratory distress syndrome in communities.[11,12] Several public health investigations anticipated concerns about hospital capacity being overwhelmed by the patient surge of confirmed COVID-19 patients in the United States, specifically in regard to potential shortages of ICU beds, negative pressure rooms, and isolation units.[13] These investigations emphasized the growing need for ICU care and ventilator support for COVID-19 patients in the United States.[14,15]

Success in responding to public health emergencies requires access to real-time data that can help track critical hospital resources for maintaining health care functionality during emergencies such as the COVID-19 pandemic.[16] The COVID-19 pandemic has demonstrated a need for innovative technical and organizational strategies that can track hospital capacity data and be used to inform key partners (eg, federal, state, and local public health entities) to take timely action to maintain supply chains and routine operations during similar emergencies. However, data on the use of such tools for situational awareness of critical resources such as ICU and ED bed use and ventilators during public health emergencies are limited. Our research is focused on the utility of a novice surveillance tool for detecting, characterizing, and monitoring the impact of COVID-19 on US health care systems. To gather timely information, the Health Pulse platform collects information from US hospitals by using an alert-based framework that identifies the daily status of hospital capacity, including ED and ICU bed availability, supply levels (eg, PPE, ventilators), and disruptions in hospital operations (eg, hospital closures). In this study, we analyzed Health Pulse data from March 7, 2020, through April 30, 2021, to assess the extent to which several US hospitals experienced ED and ICU overcrowding and ventilator shortages during the COVID-19 pandemic.

Methods

CDC and the Association of State and Territorial Health Officials, in partnership with Talus Analytics, developed the Health Pulse surveillance system.[17] Health Pulse is a web-based surveillance system that receives voluntarily shared, hospital-level data for 625 enrolled hospitals in 29 states. Health Pulse receives data directly from its partners (eg, hospital systems, state health departments) that, in turn, collect data from participating hospitals via existing data and reporting streams. The data are received from approximately 10% of US hospitals, including those with 24/7 EDs and ICUs.[18] Partners submit hospital data to Health Pulse with an approximately 1-day lag period, and data transformations are performed by using an automated Python script; resulting alerts are stored in an internal PostgreSQL database. These data include bed and patient counts, ED and ICU volume, supply levels (eg, PPE, ventilators), and disruptions in hospital operations, such as hospital closures, power outages, and hospital evacuations caused by natural disasters (eg, hurricanes, wildfires). Hospital-level data are submitted to Health Pulse overnight, and automated software scripts process these data nightly. Health Pulse uses these data to generate various alerts, including alerts on ED and ICU overcrowding, ventilator and PPE shortages, facility closures, power outages, and facility evacuations, based on pre-established thresholds for each alert type. These alerts are identified by date, alert type, the reporting hospital's state and county, and a unique, anonymized hospital identifier. We analyzed data from a convenience sample of 625 participating hospitals in 29 states for the following 3 alert types only: ED overcrowding, ICU overcrowding, and ventilator shortages. We did not include data on hospital operation disruption and PPE shortage alerts in this study because data for these alerts were available only from a small proportion of participating hospitals.

Health Pulse calculates alert thresholds for ED and ICU overcrowding using patient census and bed occupancy in EDs and ICUs. Where data for both patients and beds counts are available, Health Pulse defined ICU and ED overcrowding alerts as reaching or exceeding 100% bed occupancy. Where only data for the daily count of patients registered in the ED and ICU were available, Health Pulse generated hospital alerts when the number of registered patients was 2 SDs or higher than pre-pandemic baseline averages for patient volume. In addition, Health Pulse used 2 scoring systems, the National Emergency Department Overcrowding Scale[19] and the Emergency Department Work Index,[20] to generate alert thresholds for ED overcrowding. Health care system administrators and directors use these scoring systems that evaluate ED overcrowding to track ED crowding and for surge plan management and emergent event notification. Health Pulse generated

Table. Percentage of hospitals reporting alerts, by alert type and hospital size, Health Pulse, 29 states, March 7, 2020–April 30, 2021[a]

Alert type	Hospitals with alerts, no. (%) (N = 393)	Hospital size, no. (%)[b]				Average alert duration, d
		Small (<50 beds)	Medium (50-399 beds)	Large (≥400 beds)	Unknown hospital size	
ED overcrowding[c]	246 (63)	31 (13)	157 (64)	27 (11)	31 (13)	2.8
ICU overcrowding[d]	239 (61)	17 (7)	156 (65)	28 (12)	38 (16)	3.8
Ventilator supply shortage[e]	48 (12)	19 (40)	18 (37)	2 (4)	9 (19)	14.2

Abbreviations: ED, emergency department; ICU, intensive care unit.
[a]Data source: Talus Analytics.[17]
[b]Data on hospital size were available for 459 of 625 enrolled hospitals.[21]
[c]Data used to determine ED overcrowding alerts were available from 453 of 625 enrolled hospitals.
[d]Data used to determine ICU overcrowding alerts were available from 365 of 625 enrolled hospitals.
[e]Data used to determine ventilator alerts were available from 328 of 625 enrolled hospitals.

alerts on ventilator shortages when a hospital reached or exceeded 90% ventilator use.

We calculated the average alert duration based on the mean number of consecutive days that a hospital experienced the same type of alert. We categorized responding hospitals into 3 categories (small [<50 beds], medium [50-399 beds], and large [≥400 beds]) based on bed count data captured from the Homeland Infrastructure Foundation-Level Data.[21] We assessed trends in hospital alerts individually and counts of hospitals by alert type and hospital size. COVID-19 case data (7-day average for new cases) from the 29 states in which reporting hospitals were located were accessed from CDC's COVID-19 data.[22] Standard data transformation, calculations, and graphing tools in Python release 3.7.4 (Python Software Foundation) and Microsoft Excel (Microsoft Corp) were used for all data processing and descriptive analyses. This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy.[23]

Results

Of 625 enrolled hospitals that reported data to Health Pulse, 29 states were represented, and most hospitals (n = 581, 85%) were in urban areas. From March 7, 2020, through April 30, 2021, 393 (63%) hospitals reported at least 1 type of alert during the study period, more than half of which reported ED (n = 246, 63%) and ICU (n = 239, 61%) overcrowding alerts (Table). Only 48 (12%) hospitals reported ventilator shortage alerts.

Trends in hospital alerts paralleled surges in COVID-19 cases, particularly for overcrowding in ICUs (Figure). The overall percentage of hospitals reporting ICU overcrowding alerts (based on 7-day rolling average calculations of the daily percentage of hospitals with alerts) increased from 4% for the week ending March 13, 2020, to 11% for the week ending April 30, 2021, and averaged 11% during the study period. Initially, ICU alerts increased between the weeks ending March 13, 2020, and April 10, 2020, from 4% to 7%. These alerts remained high and steady in summer 2020, reaching as high as 13% in August 2020. Then, the largest increase (by 14 percentage points) in ICU alerts occurred between the weeks of September 4, 2020, and January 15, 2021, from 8 to 22 percentage points. Following this increase, ICU overcrowding alerts sharply declined to 8% in mid-March and gradually increased until the end of the study period.

Similarly, we observed an overall average percentage of weekly ED overcrowding alerts, with an increase from 5% to 8% during the study period. ED overcrowding alerts initially decreased from 5% for the week ending March 13, 2020, to 1% for the week ending March 27, 2020, and then started to increase in summer 2020 between the weeks ending May 8, 2020 (1%), and July 10, 2020 (7%). We observed another increase in ED overcrowding alerts in late winter/early spring 2021, from 2% for the week ending February 5, 2021, to 8% for the week ending April 30, 2021.

Ventilator shortage alerts were most frequently reported in March and April 2020. Thereafter, ventilator shortage alerts tapered off, steadily hovering at 1% through the remainder of the study period (Figure).

Of 246 hospitals that reported ED overcrowding alerts and 239 hospitals that reported ICU overcrowding alerts, more medium-sized hospitals (50-399 beds) reported ED overcrowding alerts (n = 157, 64%) and ICU overcrowding alerts (n = 156, 65%) than small-sized hospitals (<50 beds) (ED overcrowding alerts: n = 31, 13%; ICU overcrowding alerts: n = 17, 7%) and large-sized hospitals (≥400 beds) (ED overcrowding alerts: n = 27, 11%; ICU overcrowding alerts: n = 28, 12%) (Table). Small-sized hospitals reported the most ventilator shortages (n = 19, 40%).

Lastly, the alert duration varied by alert type, with an average of 2.8 consecutive days for ED overcrowding, 3.8 days for ICU overcrowding, and 14.2 days for ventilator shortages (Table).

Discussion

During the study period, the COVID-19 pandemic burdened US hospitals with patient surges and supply shortages. Our

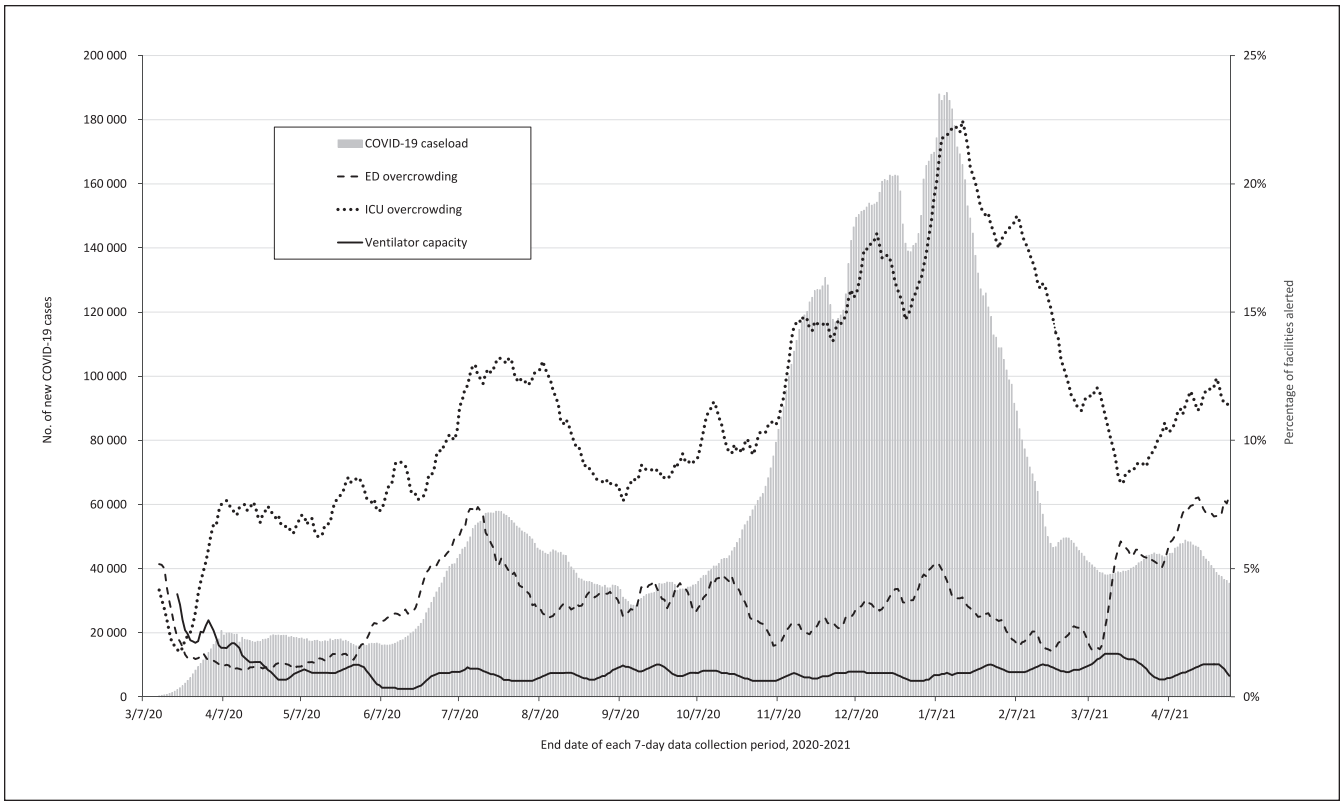

Figure. Trends in alerts for ED and ICU overcrowding and ventilator shortages at 625 hospitals in 29 states, Health Pulse, March 7, 2020–April 30, 2021. Note: Each data point (colored lines and bars) represents a 7-day average, plotted on the end date of the 7-day window. Data sources: Alert data are from Health Pulse[17] based on data shared by state and health care system partners. Case data are from US COVID-19 Cases and Deaths by State at data.cdc.gov for the 29 states included in this study.[22] Abbreviations: ED, emergency department; ICU, intensive care unit.

analysis showed that nearly two-thirds of participating hospitals reported alerts for overcrowding in EDs and ICUs and ventilator shortages. Furthermore, trends in overcrowding alerts paralleled surges in COVID-19 cases during the study period. Although the number of ICU alerts from reporting hospitals initially increased, the number of ED overcrowding alerts decreased during the same period. This initial decrease in ED overcrowding alerts may have corresponded with the COVID-19 pandemic emergency declaration in March 2020, as the number of people seeking care unrelated to COVID-19 decreased to avoid exposure to SARS-CoV-2 and when community transmission of SARS-CoV-2 was minimal.[24,25] ED and ICU overcrowding alerts increased during spring 2020, as COVID-19 spread through the community. Alerts continued to follow trends in COVID-19 cases, peaking in late summer and increasing again by winter 2020-2021. We observed ventilator shortage alerts from relatively few participating hospitals compared with ED and ICU overcrowding alerts. This finding might be the result of implementation of mitigation strategies in response to supply shortages during the pandemic.[26] To address the inability of hospitals to keep a sufficient supply and availability of ventilators, the US Food and Drug Administration (FDA) issued an umbrella Emergency Use Authorization of FDA-cleared ventilators for use in health care settings during the COVID-19 pandemic.[27] In addition, some hospitals may have started to use contingency and more conventional surge management plans during the pandemic, such as using invasive ventilation as a last resort or using alternate measures, including the use of high-flow O_2, volume-controlled, and pressure-controlled modes of ventilation (ie, prone ventilation) instead.[28]

We also observed that among participating hospitals, alerts for ventilator shortages were more frequently received from small-sized hospitals than from larger hospitals. During the COVID-19 pandemic, most hospitals experienced issues in operations disruption and resource scarcity. It is possible that these issues were more pronounced among smaller hospitals than among larger hospitals because of infrastructure differences and inadequate response capabilities (ie, fewer ICU beds, smaller supplies of ventilators, shortages of specialized staff to care for critically ill patients). During March 23-27, 2020, the US Department of Health and Human Services (HHS) conducted brief telephone interviews (“pulse surveys”) among hospital administrators from 323 hospitals in 46 states, the District of Columbia, and Puerto Rico. In the self-reported

HHS surveillance report, during the early phase of the pandemic, isolated and small hospitals faced more challenges for accessing crucial hospital supplies, including ventilators, compared with larger hospitals. In addition, some small hospitals described larger hospitals as being prioritized for receiving ventilator supplies. As a result, smaller hospitals experienced substantial ventilator shortages and had to implement contingency plans such as repurposing alternative machines from other hospitals to treat COVID-19 patients.[13]

During public health emergencies, federal agencies including CDC, the Federal Emergency Management Agency, the Centers for Medicare & Medicaid Services, and the FDA collaborate to develop crisis standards of care strategies for health care facilities to operate effectively and efficiently when there are not enough resources to give all patients the quality of care they would receive under normal circumstances.[29] CDC responds to public health emergencies by providing research-based guidance for health care facilities, health care providers, schools, communities, and the general population.[30] For example, during the initial phase of the COVID-19 pandemic, CDC released interim guidance for optimizing PPE supply in health care facilities and strategies for maintaining health care services.[31] To further mitigate the impact of supply shortages and overcrowding, CDC provides guidelines for establishing alternate care sites, such as school buildings, fairgrounds, and vacant college dormitories, as additional venues where patients with COVID-19 can remain on-site to receive medical care for the duration of their isolation period.[32] This guidance provides critical infection prevention and control considerations for alternate care sites as part of the pandemic planning. Furthermore, CDC develops strategies for the use of telehealth services to expand access to essential health services during the pandemic to maintain continuity and quality of care.[33] During the COVID-19 public health emergency, Congress passed the Coronavirus Preparedness and Response Supplemental Appropriations Act[34] for expanding the types of waivable provisions to address the difficulties of providing health care in exigent circumstances. Under the section 1135 waiver authority[35] of the Coronavirus Preparedness and Response Supplemental Appropriations Act, the Centers for Medicare & Medicaid Services expanded the telehealth benefit for Medicare beneficiaries to "receive a wider range of services from their doctors without having to travel to a health care facility."[36]

Limitations

This study had several limitations. First, Health Pulse hospital alert data were collected from 5 voluntarily participating health systems in 29 states, representing approximately 10% of all US hospitals, and most were in urban areas. Therefore, the findings of this study cannot be generalized to all hospitals in the United States. Second, data on hospital size, which can be used to identify the severity of impact by hospital size and plan for future public health emergencies, were unavailable from more than 25% of participating hospitals. Finally, our analysis did not identify other factors, such as hurricanes or wildfires, that could have contributed to operational disruptions of health care systems during the study period.

Conclusions

Timely assessment and communication on the status of the US health care system during emergencies can guide public health response efforts with targeted guidance, tools, and strategies to operate effectively and safely. Our analysis illustrates how closely trends in facility alerts aligned with COVID-19 case counts, further demonstrating that near–real-time tracking systems could provide critical information about resource shortages and contribute to planning for future public health emergencies. Understanding the real-time impact of public health emergencies on hospital operations resulting from supply and hospital bed shortages is essential for maintaining appropriate resources, fostering a safe working environment for health care personnel, and delivering safe patient care. In recognition of the importance of providing high-quality, accessible, and timely hospital capacity information, similar customized systems including the National Healthcare Safety Network,[37] HHS Protect,[38] and the National Syndromic Surveillance Program[39,40] were developed to track infections and prevention process measures in systematic ways using hospital-specific data (eg, inpatient and ICU bed use, percentage of inpatient beds occupied by COVID-19 patients, number of COVID-19 cases). However, perennial challenges exist for linking, combining, and disseminating data across multiple data collection systems because of many factors, including inconsistencies in definitions used by health care systems to describe hospital capacity and resources (eg, PPE consumption rate). These data challenges underscore the need to improve the existing health care data ecosystem to yield more interoperable data that inform risk assessment and public health response so that timely action can be taken in maintaining the supply chain and managing operations during public health emergencies.

The results of this study demonstrate a new approach to health care system surveillance by providing ongoing visibility on health care system impacts beyond the current pandemic, including the potential to inform when and where to activate other emergency response systems and actions. A coordinated approach by key partners (eg, government, health care systems, academia, private industry) that provides near–real-time visibility on health care operations during public health emergencies and crisis recovery phases is needed. Such collaborative planning and capacity-building strategies can better prepare and support the US health care system during future public health emergencies. Furthermore, expanding the geographic coverage of Health Pulse to more states and rural areas could further improve the identification of resource shortages and operation

disruptions on the US health care system during public health emergencies such as COVID-19 and intersecting events (eg, natural disasters, seasonal flu, and other pandemics).

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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