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Patterns in the Pandemic: Disproportionate Patient Burdens Among Regional Hospitals



Joseph P. Corcoran IV, MD*; Frederick V. Ramsey, PhD; Joseph M. Franzen, MD; Robert T. Bryan, DO; Anthony V. Coletta, MD, MBA

*Corresponding Author. E-mail: Joseph.Corcoran@TowerHealth.org.

Study objective: To examine the distribution of hospitalized COVID-19 patients among adult acute care facilities in the Greater Philadelphia area and identify factors associated with hospitals carrying higher burdens of COVID-19 patients.

Methods: In this observational descriptive study, we obtained self-reported daily COVID-19 inpatient censuses from 28 large (>100 beds) adult acute care hospitals in the Greater Philadelphia region during the initial wave of the COVID-19 pandemic (March 23, 2020, to July 28, 2020). We examined hospitals based on their size, location, trauma certification, median household income, and reliance on public insurance. COVID-19 inpatient burdens (ie, beds occupied by COVID-19 patients), relative to overall facility capacity (ie, total beds), were reported and assessed using thresholds established by the Institute of Health Metrics and Evaluation to approximate the stress induced by different COVID-19 levels.

Results: Maximum (ie, peak) daily COVID-19 occupancy averaged 27.5% (SD 11.2%) across the 28 hospitals. However, there was dramatic variation between hospitals, with maximum daily COVID-19 occupancy ranging from 5.7% to 50.0%. Smaller hospitals remained above 20% COVID-19 capacity for longer (small hospital median 27.5 days [interquartile range {IQR}: 4 to 32]; medium hospital median 18.5 days [IQR: 0.5 to 37]; large hospital median 13 days [IQR: 6 to 32]). Trauma centers reached 20% capacity sooner (median 19 days [IQR: 16-25] versus nontrauma median 30 days [IQR: 20 to 128]), remained above 20% capacity for longer (median 31 days [IQR: 11 to 38]; nontrauma median 8 days [IQR: 0 to 30]), and had higher observed burdens relative to their total capacity (median 5.8% [IQR: 2.4% to 8.3%]; nontrauma median 2.5% [IQR: 1.6% to 2.8%]). Urban location was also predictive of higher COVID-19 patient burden (urban median 3.8% [IQR: 2.6% to 6.7%]; suburban median 2.2% [IQR: 1.5% to 2.8%]). Heat map analyses demonstrated that hospitals in lower-income areas and hospitals in areas of higher reliance on public insurance also exhibited substantially higher COVID-19 occupancy and longer periods of higher COVID-19 occupancy.

Conclusion: Substantial discrepancies in COVID-19 inpatient burdens existed among Philadelphia-region adult acute care facilities during the initial COVID-19 surge. Trauma center status, urban location, low household income, and high reliance on public insurance were associated with both higher COVID-19 burdens and longer periods of high occupancy. Improved data collection and centralized sharing of pandemic-specific data between health care facilities may improve resource balancing and patient care during current and future response efforts. [Ann Emerg Med. 2022;80:291-300.]

Please see page 292 for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background and Importance

In the aftermath of previous viral pandemics, researchers have recommended using centralized data sharing and resource leveling to better manage patient flow and direct resources to the areas with the greatest need.¹⁻³ This strategy leverages groups of individual facilities as a collective and offers a way for the entire health care system to withstand strains that might otherwise overwhelm individual institutions. Studies have demonstrated that nonzero levels of resource-intensive, highly contagious, and potentially fatal diseases have detrimental effects on the

clinical outcomes of other hospital patients, even in cases where the critical disease or infection does not account for a majority of the hospital's census.⁴⁻⁶ In these cases, resource pooling may be similarly beneficial at reducing the strain on a single hospital by dispersing the resource and staffing demands among multiple institutions.⁴

Despite an abundance of postpandemic literature recommending it, centralized, transparent data sharing between hospitals for the explicit purpose of allocating supplies during and after a pandemic has never been widely adopted.⁷ As a result, in the initial months of the COVID-19 pandemic, many local and regional governments operated

Editor’s Capsule Summary

What is already known on this topic

Anecdotally, the COVID-19 pandemic disproportionately affected select hospitals in the same general geographic area.

What question this study addressed

Was there differential COVID-19 patient burden among adult acute care facilities with more than 100 inpatient beds in the Greater Philadelphia region? What factors influenced COVID-19 occupancy?

What this study adds to our knowledge

There was marked variation in the COVID-19 hospital occupancy in Philadelphia. Hospitals serving lower-income areas and a higher proportion of publicly insured patients had more COVID-19 patients and more COVID-related bed days.

How this is relevant to clinical practice

Better data sharing and coordination across hospitals and regions is needed if we are to reduce disparities and ensure equitable access to care.

without readily available transparent data, increasing surge capacities through the construction of field hospitals and stockpiling limited resources as they attempted to cobble together hospital-level data from disparate health systems.^{8,9}

In Philadelphia, concern that a surge in COVID-19 hospitalizations would overwhelm regional hospital capacity led multiple hospitals to convert nontraditional spaces into patient rooms and even prompted the city government to open a COVID-19 surge facility.^{10,11} Although the surge in infections never overwhelmed the region’s total bed capacity, individual hospitals reported resource, staff, and bed shortages, culminating in some hospitals needing to transfer patients.¹⁰ Despite attempts by the regional government to level the COVID-19 censuses by encouraging interhospital patient transfers, it became increasingly clear that hospitals were bearing different burdens of COVID-19 cases.

Goals of This Investigation

This study assesses available COVID-19 inpatient census data to examine the distribution of disease burden among adult acute care facilities in the Greater Philadelphia region during the initial wave of COVID-19. We assess this primary objective based on 2 conceptual data axes—comparisons of hospital-specific or group-specific COVID-19 occupancies and the timing (ie, temporal

occurrence/variation) of those occupancies. The secondary objective was to evaluate facility-level and catchment-area factors (facility size, location, trauma center status, median household income, and reliance on public insurance) to see which factors might influence COVID-19 occupancy levels. We assess this secondary objective through descriptive statistics and the use of heat maps. Additionally, we consider recommendations for augmenting data-driven regional responses to future pandemics.

MATERIALS AND METHODS

Study Area and Design

The Greater Philadelphia region consists of Philadelphia County and its neighboring 4 counties (Montgomery, Chester, Bucks, and Delaware) (Figure 1). Located in Southeastern Pennsylvania, it spans 2,170 square miles and has a socioeconomically diverse population of 4.1 million.¹² The region contains 68 hospitals, including 40 adult acute care facilities and 28 specialty hospitals (eg, children’s hospitals, psychiatric institutions, and inpatient rehabilitation clinics).

In anticipation of a surge of COVID-19 hospitalizations in March 2020, Pennsylvania’s Department of Health mandated the reporting of hospital-level data on confirmed COVID-19 cases, bed availability, ventilator availability, and other related variables such as personal protective equipment availability. The reporting of baseline hospital occupancy data (ie, pre-COVID-19 average patient census), total hospital census data, and non-COVID-19

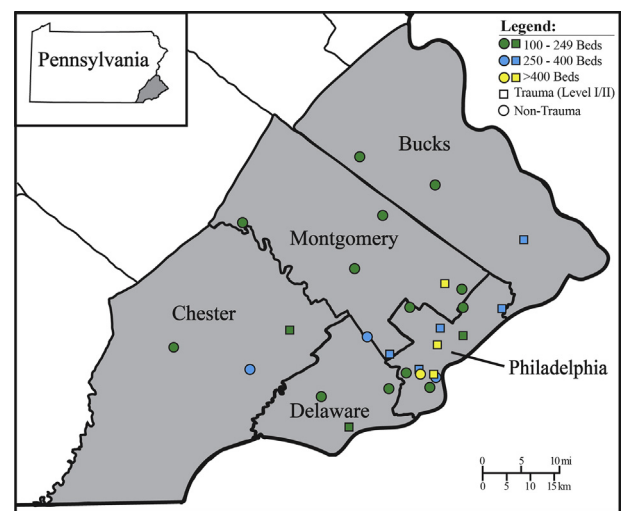


Figure 1. Adult acute care facilities (≥100 beds) in the Greater Philadelphia region (Philadelphia County and the neighboring counties of Delaware, Chester, Bucks, and Montgomery) were considered in this study. Hospitals are color coded by total bed count (sum of medical/surgical and ICU beds). The squares represent certified trauma centers (levels I and II), and the circles represent hospitals that are not trauma centers.

census data were not mandated, and therefore, those data were not available for this analysis.

The COVID-19 census data were self-submitted to the Department of Health by all Pennsylvania hospitals twice daily between March 23, 2020, and July 28, 2020. Regional data pertaining to the 68 hospitals in the Greater Philadelphia region were made available to the Philadelphia Office of Emergency Management for situational awareness and planning purposes and were amassed by the Office of Emergency Management in an online tracking dashboard.¹³ The online dashboard provided real-time context to county governments about regional readiness and the level of strain on different health systems, and it provided at-a-glance appraisals of the state of the pandemic. These data were accessed by the authors through their clinical roles in the city's response. However, given their potentially sensitive nature, the data were not shared between local hospitals and health systems. This study is an observational, descriptive reporting of hospital COVID-19 occupancy based on a secondary analysis of data reported by the hospitals.

Given that this study is a secondary analysis of a pre-existing, aggregated, hospital-level dataset that includes no identifiable patient data, it does not qualify as human subject research and an institutional review board exemption was neither sought nor necessary.

Data Acquisition and Preprocessing

Inpatient census data were mined from the Office of Emergency Management dashboard from March 23, 2020, through July 28, 2020. No patient-identifying information was collected. Inpatient censuses were collected for all acute care and specialty facilities in the region (n=68).

Specialty and pediatric hospitals (n=28) and hospitals with fewer than 100 total beds (n=11), were excluded. One of the remaining large (>100 beds) adult acute care facilities was excluded due to incomplete data reporting. The remaining 28 large adult acute care facilities were included in this study.

Given the sensitive nature of our data, care was taken to prevent the connection of any specific hospital to its data. Aside from geographical location, the identifying features of the hospitals in this study were removed. COVID-19 levels were reported as proportions of total bedspace rather than as raw counts. This allowed us to compare facilities with different bed counts by normalizing for hospital size and prevented the connection of COVID-19 occupancy data with specific facilities.

Although hospitals reported data twice daily, only the afternoon submissions were used in analysis because the afternoon data were judged to be most representative of daily censuses. Data completeness was very high ($\geq 98\%$

completeness), and missing data periods were very short (mean length of missing data blocks was 1.2 days, SD 0.8). Missing data were imputed based on the preceding or following census values. Only confirmed COVID-19 cases were included in this analysis. However, since data were self-reported by each facility, the specific criteria needed to confirm a COVID-19 diagnosis may have differed between hospitals.

Hospital Capacities

Hospital capacity was determined by summing the medical or surgical and ICU bed counts reported by each hospital at 2 time points. Many hospitals transformed nontraditional spaces into additional bed spaces to increase capacity.¹⁴⁻¹⁶ Therefore, we preferentially selected the higher reported bed counts to account for surge capacities, thereby providing conservative percent estimates of hospital COVID-19 capacity levels.

Hospital census data were used to examine the number of days that a particular facility reported COVID-19 inpatient hospitalizations above various thresholds of total capacity. Thresholds were adapted from models put forth by the Institute for Health Metrics and Evaluation (IHME)¹⁷ and reflect the stress placed on a facility as the COVID-19 inpatient occupancy grows (per IHME, COVID-19 levels <5% of total capacity are considered low stress, levels 5% to <10% are considered moderate stress, levels 10% to <20% are considered high stress, and levels $\geq 20\%$ are considered extreme stress). Our additional threshold of more than 30% was chosen to provide additional granularity in COVID-19 occupancy levels among hospitals experiencing extreme stress ($\geq 20\%$ COVID-19 occupancy).

Hospital burdens were calculated by summing the daily totals of COVID-19 patients at each facility. This metric was a proxy for work done by each hospital to care for COVID-19 patients across a specific time frame. Total COVID-19 burden for the 28 hospitals across the 128 days in this study was 89,539 COVID patient days. The proportion of the total COVID-19 patient days that was shouldered by an individual facility was considered the "observed burden."

Hospital Partitions

Hospitals were partitioned based on size, location, and trauma certification. To maintain hospital anonymity, the size was analyzed as a binned variable (bed count 100 to 249 beds, 250 to 400 beds, and >400 beds) rather than as a continuous variable. Location and trauma certification were treated as binary variables (ie, suburban or urban, trauma center or not).

Trauma center certification, in particular, was studied given the critical role that Pennsylvania trauma centers play in the care of high-acuity patients,¹⁸ including in nontrauma presentations (such as COVID-19). In Pennsylvania, trauma center designation requires numerous capabilities above and beyond nontrauma facilities. These include the 24×7 in-house presence of airway specialists (anesthesiologists, emergency physicians, and respiratory therapists), pharmacy, laboratory and blood bank personnel, trauma surgeons, and a dedicated ICU physician team.¹⁹ Additionally, trauma centers must have the ability to receive patients by land or air, must maintain specialized equipment such as cardiopulmonary bypasses, and have refined capabilities to accept referrals and transfers from other facilities.¹⁹ In short, they are more effectively equipped to manage complex and critically ill patients, even if those patients are not presenting for trauma-related reasons.¹⁹

Hospitals were also partitioned based on the socioeconomic status of their service area. Due to the lack of publicly available hospital catchment data, zipcode-level data were used as a proxy. Specifically, the median household income and the percentage of the population in a given zipcode that rely on public insurance were studied. Both variables were binned into similarly sized subgroups to ensure hospital anonymity (income: <\$50,000, \$50,000 to <\$90,000, >\$90,000; publicly insured: <28%, 28% to <38%, >38%). Median household income data and reliance on public insurance data were mined from the US Census Bureau and reflect 5-year averages (2014 to 2019).²⁰

Statistical and Data Analyses

Categorical data were summarized as counts and percentages. Continuous data were summarized as mean (SD) or median (IQR) as appropriate. After obtaining and inspecting the data, 2 approaches (quantitative statistics and descriptive heat maps) were identified as appropriate methodologies to address the study objectives. For time-to-peak for COVID-19 occupancies, given that each hospital or group of hospitals peaked (although peaked at different times), the analyses of times-to-peak for COVID-19 occupancies were based on comparisons of simple means.

The secondary objective (ie, the evaluation of facility-level and catchment-area factors affecting occupancy) was assessed descriptively using temporal heat maps. For each hospital during the 128-day study period, daily COVID-19 occupancies were described based on the 5 stress categories derived from IHME: less than 5% of total hospital capacity (minimal stress), 5% to less than 10% (moderate stress),

10% to less than 20% (high stress), 20% to less than 30% (extreme stress), and 30% or more (severe stress). Hospitals were then grouped based on the analysis factor and daily stress values plotted for the 128-day study period. Statistical analyses and heat mapping were conducted using SAS 9.4 (SAS Institute).

RESULTS

Hospital Descriptions

There are 29 large (>100 beds) adult acute care hospitals in the Greater Philadelphia region. One of these facilities was excluded due to incomplete data reporting. The census data for the remaining 28 large adult acute care facilities were tracked for 128 days (March 23, 2020, to July 28, 2020). Of these 28 facilities, 12 were in Philadelphia County (Figure 1). The remaining 16 were spread between the suburban counties of Montgomery (7), Chester (3), Bucks (3) and Delaware (3). The 28 hospitals included 8 separate health systems (and 3 independent facilities) and 11 trauma centers (4 level I and 7 level II).

Of a total of 7,254 staffed beds, 47% were concentrated among 1 quarter of the hospitals, and approximately half (54.3%) were concentrated in Philadelphia County. Bed counts ranged from 101 to 802 beds per hospital ($x=259$, SD 175). Median household income for the ZIP codes containing the hospitals ranged from \$22,790 to \$132,219 ($x=\$70,017$, SD \$30,415), and reliance on public insurance ranged from 23.7% of the zipcode population to 63.5% ($x=35.6\%$, SD 11.3%).

COVID-19 Inpatient Levels at Individual Hospitals

Between March 23, 2020, and July 28, 2020, COVID-19 hospitalizations varied dramatically between hospitals and over time (Figure 2). Of the 28 total hospitals, 27 spent at least 1 day with COVID-19 occupancy more than 10%, 21 spent at least 1 day with occupancy more than 20%, and 11 reported at least 1 day with COVID occupancy more than 30%.

The number of days facilities were above certain COVID-19 levels was not uniform. On average, hospitals spent 19.6 days with more than 20% COVID-19 levels, but several hospitals spent 40 or more days above 20%. Three facilities (10.7%) reported 1 or more days with COVID-19 levels above 40%, with 1 facility spending 13 days above 40% COVID-19 levels. Conversely, 7 hospitals had no days with more than 20% COVID-19 occupancy.

Maximum (ie, peak) daily COVID-19 occupancy averaged 27.5% (11.2% SD) across the 28 hospitals, with

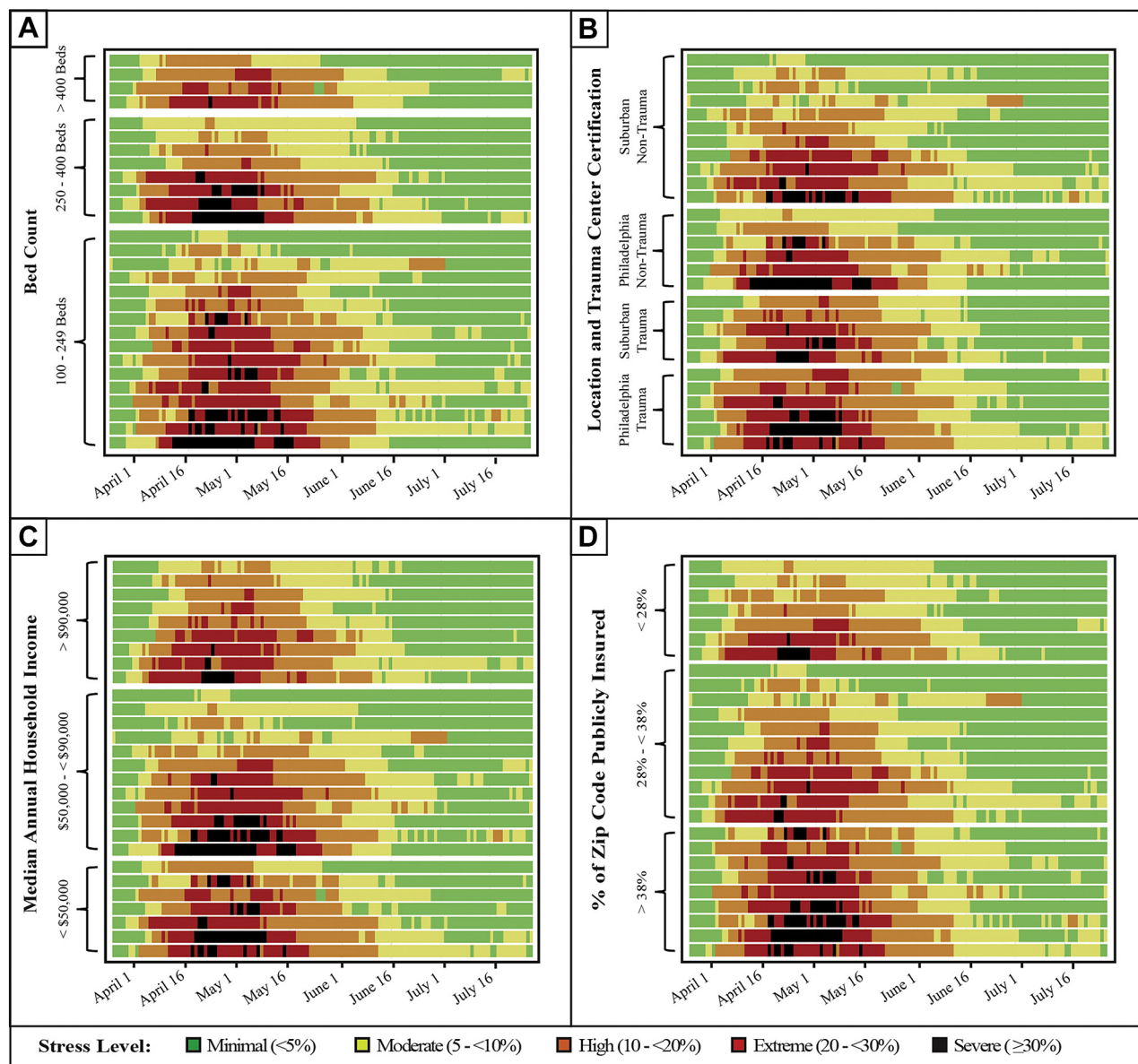


Figure 2. Daily COVID-19 inpatient levels at adult acute care facilities in the Greater Philadelphia region, represented as the percentage of available beds filled by COVID-19 patients. Stress thresholds were established by the Institute of Health Metrics and Evaluation (14) and have been adjusted by the authors to include a fifth threshold ($\geq 30\%$). Facilities are subgrouped the number of beds (A), trauma certification and location (B), the median household income in the zipcode where the hospital is located (C), and the percentage of individuals within a hospital’s zipcode who are publicly insured (D). Within each subgroup, facilities are arranged from the facilities with the lowest occupancy to the facilities that had the highest overall occupancy.

dramatic variation between hospitals (maximum daily COVID-19 occupancy ranging from 5.7% to 50.0%). Nearly all hospitals (27 of 28) reached their single day maximum COVID-19 census within 22 days of each other (April 20, 2020, to May 12, 2020). The highest cumulative COVID-19 volume occurred on April 24, 2020, with a cumulative census of 1,576 COVID-19 hospitalizations (21.7% of the region’s total adult acute care bed capacity), 1 day after the Philadelphia County censuses peaked on

April 23 (885 COVID-19 inpatients, 22.5% of total capacity).

Hospital Size

Mean hospital COVID-19 occupancy over the 128-day study period was not associated with hospital size (Table 1). However, mean occupancy for individual hospitals varied substantially, ranging from mean COVID-19 occupancies

Table 1. Hospital size, mean COVID-19 occupancy, and days with ≥20% COVID-19 occupancy.

Hospital Size	Mean COVID-19 Occupancy	Range	Median Days With 20% or Higher COVID-19 Occupancy
100-249 beds (n=16)	10.1% (SD 4.1%)	1.9%-16.8%	28 days (n=16, IQR: 4-32)
250-400 beds (n=8)	10.1% (SD 4.3%)	5.2%-15.9%	18 days (n=8, IQR: 0-37)
>400 beds (n=4)	9.5% (SD 2.8%)	5.6%-11.9%	13 days (n=4, IQR: 6-32)

IQR, Interquartile range.

of 1.9% to 16.8%. At the extremes of the spectrum, 1 hospital carried 7.2% of the total COVID-19 burden (summed over the 128 days) despite accounting for only 4.4% of the cumulative beds, whereas another carried 6.2% of the total burden despite accounting for more than 10% of the cumulative beds.

Days at 20% or higher COVID-19 occupancy (ie, extremely stressed as defined by IHME) were inversely related with hospital size (Table 1). Smaller hospitals were extremely stressed (ie, over 20% COVID occupancy) 2.2 times longer than large hospitals and 1.6 times longer than medium hospitals.

Interhospital Distinctions Based on Location and Trauma Status

Philadelphia County’s cumulative volume peaked 1 day ahead of the combined suburban counties (April 23 versus April 24). Urban hospitals reached their single day maximums a median of 3.5 days earlier, peaked at higher occupancy levels, filled to 20% more quickly, and remained above the 20% threshold longer compared with suburban hospitals (Figure 2, Table 2). Similarly, trauma centers filled to 20% capacity more quickly than nontrauma centers, remained above 20% capacity for longer, and peaked at higher levels overall (Table 3).

Interaction Between Location and Trauma Status

When considered together, location and trauma status highlight substantial differences relative to extreme COVID-19 stress (ie, over 20% COVID-19 occupancy) (Table 4). Urban hospitals with trauma centers were

extremely stressed 1.75 times longer than urban hospitals with no trauma centers. Suburban hospitals with trauma centers were extremely stressed 30 times longer than suburban hospitals with no trauma centers. Urban hospitals with trauma centers and suburban hospitals with trauma centers had similar lengths of 20% or higher COVID-19 occupancy.

Interhospital Distinctions Based on Income and Insurance

Hospitals in lower income areas (and by implication likely serving those with a lower socioeconomic status) were more critically stressed (Table 5). Hospitals in low-income areas were extremely stressed 3.9 times longer than hospitals in higher-income areas and 1.7 times longer than hospitals in medium-income areas.

Further, we posit that the fraction of the population having public insurance is a robust surrogate for the socioeconomic status of the general population in a hospital’s service area. Hospitals serving populations with the greatest reliance on public insurance (and by implication likely serving those with the lowest socioeconomic status) were extremely stressed 4 times longer than hospitals in areas with a comparatively moderate reliance on public insurance and were extremely stressed 32 times longer than hospitals in areas with a comparatively low reliance on public insurance (Table 6).

LIMITATIONS

This research was subject to several limitations. Firstly, this study was limited to adult acute care hospitals with 100

Table 2. Comparison of COVID-19 occupancy between urban and suburban hospitals.

Hospital Location	Median Days to Single-Day Maximum	Peak Daily Occupancy Level	Median Days to First 20% Occupancy	Median Days Above 20% Occupancy
Urban	31.5 days (IQR: 29.5-37.5)	31.0% (IQR: 22.9%-36.9%)	18.5 days (IQR: 16.5-32)	29 days (IQR: 13-38)
Suburban	35.0 days (IQR: 30.5-42.0)	23.8% (IQR: 18.2%-32.4%)	27.5 days (IQR: 22 to >128)	8 days (IQR: 0-30.5)
Difference	-3.5 days (95% CI: -9.0 to 2.0)	7.2% (95% CI: -4.8 to 15.9)	-	21 days (95% CI: -2 to 26)

CI, Confidence interval.

Table 3. Comparison of COVID-19 occupancy between trauma and nontrauma hospitals.

Hospital Trauma Status	Median Days to First 20% Occupancy	Median Days Above the 20% Occupancy	Peak Daily Occupancy Level	Comment
Trauma	19 days (IQR: 16-25)	31 days (IQR: 11-38)	31.6% (IQR: 22.3%-35.7%)	11 spent 12 or more days above 20%, and 6 spent time above 30%.
Nontrauma	30 days (IQR: 20 to >128)	8 days (IQR: 0-30)	26.4% (IQR: 16.8%-31.9%)	7 never reached 20% COVID-19.
Difference	-	13 days (95% CI: 1-30)	5.2% (95% CI: -4.5% to 15.6%)	-

or more bed total capacity and excluded smaller hospitals, children's hospitals, and specialty hospitals. Although cursory inspection of available data suggests that these other hospitals were impacted by COVID-19, we proffer no opinion regarding the generalizability of our findings to these other hospital types. Secondly, although we considered 28 of the 29 regional adult acute care hospitals with 100 or more bed total capacity (where one was excluded because of data completeness issues), this sample size is unavoidably small.

Additionally, the study data were self-reported by each hospital as part of a large (≥ 100 items), twice-daily, manually reported data submission. Within this framework, we acknowledge the possibility of data errors, including measurement bias, measurement error, recording or reporting errors, and other unknown errors. Data were limited relating to intrasystem transfers, which may or may not have influenced the COVID-19 inpatient levels at some hospitals, and because of the paucity of data on historical routing patterns, we were unable to define hypothetical "expected" burdens for the hospitals. Since hospitals were not required to report their baseline census data or their non-COVID-19 census data during the pandemic, our study is fundamentally limited in which conclusions can be drawn about hospital capacity (ie, we can comment on the relatively high COVID-19 load faced by a particular hospital, but since many hospitals proactively lowered their non-COVID-19 censuses, we cannot comment on whether a hospital's total occupancy was above or below prepandemic levels).

Table 4. Interaction between location and trauma status.

Location and Trauma Status	Median Days Above 20% COVID-19 Occupancy
Urban, trauma center	35 days (n=6, IQR: 15-40)
Urban, no trauma center	20 days (n=6, IQR: 0-32)
Suburban, trauma center	30 days (n=5, IQR: 8-31)
Suburban, no trauma center	1 day (n=11, IQR: 0-30)

Managing these limitations will take a substantial effort. Disaster response planners should contemplate a "less is more" approach and carefully consider which data items are needed and how frequently they need to be updated in order to avoid further stressing understaffed facilities. We recommend streamlined data reporting of a few selected variables daily and including demographic or socioeconomic data about the hospitals' catchment areas and payer mix (Table 7). Ideally, these data would be centralized and shared publicly so that diseased individuals might be more equitably dispersed based on available resources.

Finally, our analysis includes only a cursory look at hospital catchment area demographics and socioeconomic factors, the importance of which has been previously established.^{21,22} Median household incomes based on hospital ZIP code are imperfect measures for the socioeconomic status of a hospital's wider service area but, unfortunately, were the only available data. Future studies should seek data with additional granularity, as it relates to hospital catchment area, in order to draw firmer conclusions. Hopefully, centralized data sharing will make those data considerably easier to access so that future papers will not have to contend with a lack of data.

DISCUSSION

It is well documented that increases in hospital occupancy past a certain "tipping point" correlate with worsening clinical outcomes.²³⁻²⁶ These outcomes may include reductions in quality of care, such as increases in patient mortality, nosocomial infections, adverse events,

Table 5. Income and days above 20% COVID-19 occupancy.

Income in Area Around Hospital	Median Days Above 20% COVID-19 Occupancy
Lowest (<\$50,000)	31 days (n=7, IQR: 15-40)
Medium (\$50,000-\$90,000)	18 days (n=12, IQR: 0-34)
Higher (>\$90,000)	8 days (n=9, IQR: 3-30)

Table 6. Public insurance and days above 20% COVID-19 occupancy.

Hospital	Median Days Above 20% COVID-19 Occupancy
In areas with the highest % of population with public insurance (>38%)	32 days (n=9, IQR: 26-38)
In areas with moderate % of population with public insurance (28%-38%)	8 days (n=12, IQR: 0-31)
In areas with lowest % of population with public insurance (<28%)	1 day (n=7, IQR: 0-30)

and readmission.⁶ This relationship has been studied in a variety of infectious diseases, including in H1N1, where 1% increases in acute respiratory infection admissions were associated with 0.25% increases in nonacute respiratory infection mortality,⁴ and in COVID-19, where increased COVID-19 admissions are associated with unnecessarily high mortality rates.²⁷

With regards to COVID-19, IHME has proposed 20% as that tipping point, suggesting that sustained COVID-19 levels above 20% of a facility’s capacity are detrimental to patient care and represent “extreme stress” for that facility.¹⁷ By those measures, 21 of the 28 adult acute care facilities in this study underwent a period of extreme stress at the detriment of patient outcomes. Despite this near-global stress, our data revealed that the initial COVID-19 surge took a far heavier toll on certain types of facilities compared to others.

Given that we included almost the entire population (ie, 28 of 29) of adult acute care hospitals with more than 100 beds in the Greater Philadelphia region in this analysis, we are fundamentally limited with respect to sample size and the associated analytical options. With that preface, the heat map analyses presented here provide for a robust, data-driven identification of factors associated with hospitals that experienced higher and, possibly, critically stressful levels of COVID-19 occupancy during the spring 2020 surge. In the Greater Philadelphia region, urban hospitals, trauma centers (including suburban trauma centers), smaller hospitals (ie, <250 beds), hospitals in lower income areas, and hospitals in areas of higher reliance on public insurance all exhibited substantially higher COVID-19 occupancy and substantially longer periods of high COVID-19 occupancy. Whereas the small sample size limits the potential for multivariable analyses, the joint occurrence of these factors, as demonstrated in the urban/trauma analyses, likely exacerbates the COVID-19 occupancy risks confronting select hospitals.

A more thorough multivariable analysis will be necessary to better understand the mechanisms behind the disproportionate patterns revealed by our preliminary analysis of these data, but the realities of collecting potentially sensitive data in the current health care ecosystem may limit the ability to conduct more granular analyses. Clinical and socioeconomic dynamics, including transferring acutely ill, highly contagious patients between facilities and uncertainty about rapidly evolving reimbursement mechanisms in the face of extreme financial pressure, are likely to have contributed meaningfully to the

Table 7. Recommended data collection for future disaster response scenarios.

Timing of Data Collection	Hospital-Level Data	Health System-Level Data
Predisaster data	Baseline average occupancy/census for the following: Hosp., ICU, Med/Surg, and ED Total Hosp., ICU, Med/Surg, and ED beds Staffed Hosp., ICU, Med/Surg, and ED beds Baseline staffing availability Baseline equipment availability (including PPE) Patient demographics, payer mix Catchment area	HS baseline average occupancy/census: HS, Hosp., ICU, Med/Surg, and ED Total HS, ICU, Med/Surg, and ED beds Staffed HS, ICU, Med/Surg, and ED beds Patient demographics, payer mix Catchment area
Data which should be reported daily during disaster period	Occupancy (%) and census for the following: Hosp., ICU, Med/Surg, and ED Broken down by patient admitted for disaster versus nondisaster reasons Available beds (Hosp., ICU, Med/Surg, ED) 24-hour admissions, discharges, deaths, and transfers (disaster versus nondisaster) Hosp. staffing and equipment availability	All hosp.-level data compiled for HS with breakdowns by disaster/nondisaster HS total occupancy (%) and census HS 24-hour transfers (intersystem, intrasystem)

ED, Emergency department; Hosp., hospital; HS, health system; ICU, intensive care unit; Med/Surg, medical surgical; PPE, personal protective equipment.

observed patterns.²⁸ Demographics, including population density and per capita income, as well as regional COVID-19 incidence, may have directly impacted the observed patterns when viewed through the lens of primary and secondary hospital service areas.³ Finally, the role of the self-selection of facilities by patients and their doctors requires further investigation since particular facilities (such as trauma centers) might play central roles in future pandemic responses.¹⁸ Future research should consider additional data-driven refinement and prioritization of the risk factors identified here, with the particular focus on identifying at-risk hospitals and developing risk management strategies.

However, even as we work to identify the mechanisms leading to the disproportionate distributions of COVID-19 patients, we must take certain steps to mitigate similar problems going forward. Specifically, more comprehensive data collection and more transparent data sharing will be critical both to recognize disproportionate patient distributions when they exist and to effectively allocate the staff and resources needed to mitigate or prevent them. Recommendations for improved data collection and sharing have followed every modern pandemic (1918 Spanish influenza, 1957 Asian flu, 1968 Hong Kong flu, and the 2009 swine flu)^{7,29,30} but have never been broadly applied. However, several models, including Oregon's state-wide Hospital Capacity System and New York's Health Emergency Response Data System, have demonstrated the usefulness of centralized data collection and sharing, and may provide blueprints going forward.^{31,32} These models provide regional governments with comprehensive and rapid situational awareness, allowing for quick deployment of resources and redistribution of patient loads as necessary. Furthermore, they establish the centralized collection and sharing of pandemic-specific information (Table 7) in an accurate, real-time, and incentivized (if not mandated) manner.

Establishing similar models nationwide will be imperative to obtaining equitable patient distribution and maintaining regional capacity in the face of continued surges of COVID-19 infections. This will require unprecedented transparency and intersystem cooperation but will be necessary for the American health care system to survive the enormous strain of the COVID-19 pandemic. Never before has the mandate been greater for the American health care system to function as a unit, rather than just as the sum of its parts.

Supervising editor: Richelle J. Cooper, MD, MSHS.

Author affiliations: From the Department of Emergency Medicine (Corcoran), Reading Hospital, West Reading, PA; the Department of

Clinical Sciences (Ramsey), Lewis Katz School of Medicine, Temple University, Philadelphia, PA; and the Department of Internal Medicine (Franzen), the Department of Emergency Medicine (Bryan), and the Department of Surgery (Coletta), Temple University Hospital, Philadelphia, PA.

Author contributions: JC conceived the study, collected the data and performed preliminary data analyses. JC, JF and AC developed study guidelines and drafted the initial manuscript. FR provided statistical analysis and data management. JC and FR designed the figures and tables for the manuscript. Revisions were led by JC and FR with key input from RB. AC and RB provided critical oversight to the project. JC takes responsibility for the paper as a whole.

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Future Meetings of the American College of Emergency Physicians

The following are the planned sites and dates for the future annual meetings of the American College of Emergency Physicians:

October 1-4, 2022	San Francisco, CA
October 9-12, 2023	Philadelphia, PA
September 29-October 2, 2024	Las Vegas, NV
October 27-30, 2025	Dallas, TX
October 5-8, 2026	Chicago, IL
October 25-28, 2027	Boston, MA
September 18-21, 2028	Las Vegas, NV