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RESEARCH LETTER

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Geographic distribution of bed occupancy during the COVID-19 epidemic in the United States: A nationwide study

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1 | INTRODUCTION

Since the SARS-CoV-2 pandemic started, the United States has become the global leader in confirmed cases. As of 10 December 2020, the United States had 15 271 571 confirm coronavirus disease 2019 (COVID-19) infections and 288 762 deaths. The epidemic threatens overwhelming our healthcare system, especially in areas and communities that have been well-documented to have limited access to care. Several models have aimed to predict the burden on the healthcare system in the early stages of the pandemic,[1,2] but do not adjust for many important population characteristics that impact access to care, geographic variability, or the ability of the local provider infrastructure to deliver care (eg, bed capacity). To the best of our knowledge, no papers have been published using longitudinal, retrospective data describing bed occupancy or geographic variability during the COVID-19 pandemic in the United States. As a nation, we do not have a good understanding of how the direct and indirect consequences of the COVID-19 epidemic have impacted access to healthcare in varied geographic regions or for underserved populations. The objective of this paper is to provide preliminary information describing the geographic disparities of bed occupancy across the United States during the early pandemic. In addition, we will identify states that are experiencing ongoing capacity issues.

2 | METHODS

2.1 | Data and sample

This longitudinal, observational study used data from the Department of Health and Human Services for COVID-19 estimated patient impact and hospital capacity by state from 1 April to 31 October 2020.[3-6] The daily time series datasets are estimations of inpatient, COVID-19 inpatient, and intensive care unit (ICU) beds occupied using facility-level granularity from: (a) HHS TeleTracking and (b) healthcare facilities reporting to HHS Protect by state/territorial health departments. Due to data availability and access to the datasets, there are gaps in the data from July 8-12 and August 14-30. The final dataset included 50 states and the District of Columbia (DC) for a total of 10 067 observations. We merged the data with the United States COVID-19 cases and deaths by state.[7]

2.2 | Bed capacity mapping

We mapped each state based on their highest daily occupancy over the time period to determine the geographic maldistribution on their level of risk of reaching full bed capacity. States that reached greater than 70% occupancy for either inpatient *OR* ICU beds in the time period were considered "elevated risk," greater than 70% occupancy for both were "high risk," and >99% occupancy for inpatient or ICU beds were "at or above capacity." Reasons for using a 70% threshold

were 3-fold: (a) the highest US national occupancy for the time period was near 70%; (b) similar 70% thresholds are used to describe states with the highest occupancy[8]; and (c) our data indicate fluctuations of 30% occupancy are possible as the epidemic progresses. States that have predominantly older adults are at greater risk of hospitalization from COVID-19 and account for 53% of ICU admissions.[9] Our map includes information identifying the top 10 states with the highest populations of older adults living in rural counties that do not have ICU beds.[10]

2.3 | Statistical analysis

Descriptive statistics were produced for every state over the time period to determine bed occupancy. We estimated the impact of new cases on inpatient and ICU occupancy by conducting a bivariate regression analysis. To improve data quality, we included data from May 01 to October 30 to avoid the correction errors in new cases at the beginning of the reporting period. Our primary dependent variables were the number of inpatient beds occupied by COVID-19 patients and ICU beds occupied, and the independent variable was the number of new COVID-19 cases. We used a fixed-effects generalized least squares regression with robust option to obtain heteroskedasticity-robust standard errors by the state to determine the impact of COVID-19 incidence on inpatient and ICU occupancy. Model selection was verified by conducting Hausman test where the unique errors (ui) were correlated with the regressors ($P < .001$).[11] In addition, we performed bivariate linear regressions to analyze the demand of non-COVID-19 inpatient beds over time. We considered $P < .05$ to be significant and report 95% confidence intervals (CIs) for coefficients. All analyses were computed using StataMP version 16.

3 | RESULTS

3.1 | States' greatest occupancy experienced during the epidemic and risk of reaching hospital bed capacity

From 1 April to 31 October 2020 the United States average for inpatient beds occupied by COVID-19 patients was 7.3%, 62.9% for total inpatient beds occupied, and 64% for ICU beds occupied. The states with the highest daily inpatient beds occupied were Rhode Island (102.2%), followed by Hawaii (99.3%) and Washington (91.9%). The DC (100%), Texas (99.0%), Rhode Island (94.1%), and Washington (93.8%) had the highest daily ICU bed occupancy. Out of the 50 states and DC, 72.5% (n = 37/51) had reached a maximum inpatient occupancy of 70% or greater during the time period, and 90.2% (n = 46/51) for ICU occupancy, respectively (Figure 1). There are geographic clusters of states facing a high risk of reaching capacity in the external regions of the United States. Mississippi, Missouri, Wyoming, and Vermont are identified at elevated risk of reaching capacity but are also states with a high population of older adults living in rural counties without ICU beds.[9] West Virginia, Maine, Arkansas, South Dakota, North Dakota, and Montana are also identified as the top 10 states with the highest population of older adults living in rural counties without ICU beds,[9] and are at high risk of reaching capacity for both inpatient beds and ICU beds.

Using nationwide estimates, for every 100 new COVID-19 cases we can expect 56 patients (95% CI 43.9-69.1) will be admitted to an inpatient bed ($P < .001$; $R^2 = 0.629$). For every 100 new COVID-19 cases we can expect 8 patients (95% CI 3.5-13.8) will be admitted to an ICU ($P = .001$; $R^2 = 0.448$). At the state level, there is a maldistribution of COVID-19 inpatient occupancy. The highest daily COVID-19 inpatient occupancy was 46.2% (NJ), followed by 44.8% (NY) and 41.2% (AZ), and were clustered in the south and northeast regions. Texas (99.0%) and the DC (100%) were at capacity for ICU beds during the time period and were the top 10 states for COVID-19 inpatient occupancy. Rhode Island (102.2%) reached capacity for inpatient beds and was a top 10 state for COVID-19 inpatient occupancy. Arkansas was one of the top 10 states for COVID-19 inpatient occupancy, face large populations of older adults living in rural counties without ICU beds, and have greater than 70% occupancy for inpatient and ICU beds.

3.2 | States with the highest COVID-19 occupancy have a growing demand for non-COVID-19 admissions

Arizona, Georgia, Massachusetts, Maryland, New Jersey, and New York had the highest daily inpatient beds occupied by COVID-19 patients. The northern states including Massachusetts, Maryland, New Jersey, and New York experienced peaks in COVID-19 inpatient admissions early months of the epidemic from April to June. In contrast, the southern states including Arizona and Georgia experienced peaks in COVID-19 inpatient admissions toward the middle of the time period between June and September. Temporal trends in COVID-19 inpatient beds occupied declined overall among these states, but the same declines were not seen in the percent inpatient beds occupied. Figure 2 shows the temporal change in occupancy for inpatient beds occupied by COVID-19 patients, overall inpatient occupancy, and ICU occupancy.

The nation is experiencing increased demand as the epidemic continues. Every day there was a 0.09% (95% CI 0.08-0.10) national increase in non-COVID-19 inpatient occupancy ($P < .001$; $R^2 = 0.78$). In addition, the bottom frame of Figure 2 demonstrates that non-COVID-19 related inpatient occupancy increased over the course of the epidemic for all 6 states experiencing a high hospital burden of COVID-19 patients. We found a significant positive linear relationship between non-COVID-19 inpatient occupancy and time for all 6 states ($P < .001$). Five of the six states had higher projected daily increases in non-COVID-19 admissions than the national estimate, including New Jersey (0.20%), New York (0.17%), Maryland (0.13%), Massachusetts (0.12%), and Georgia (0.11%). Arizona experienced 0.05% increase over the time period, which was below the national average.

Alabama, DC, Georgia, Maryland, Rhode Island, and South Carolina were the states with the highest occupancy over the time period.

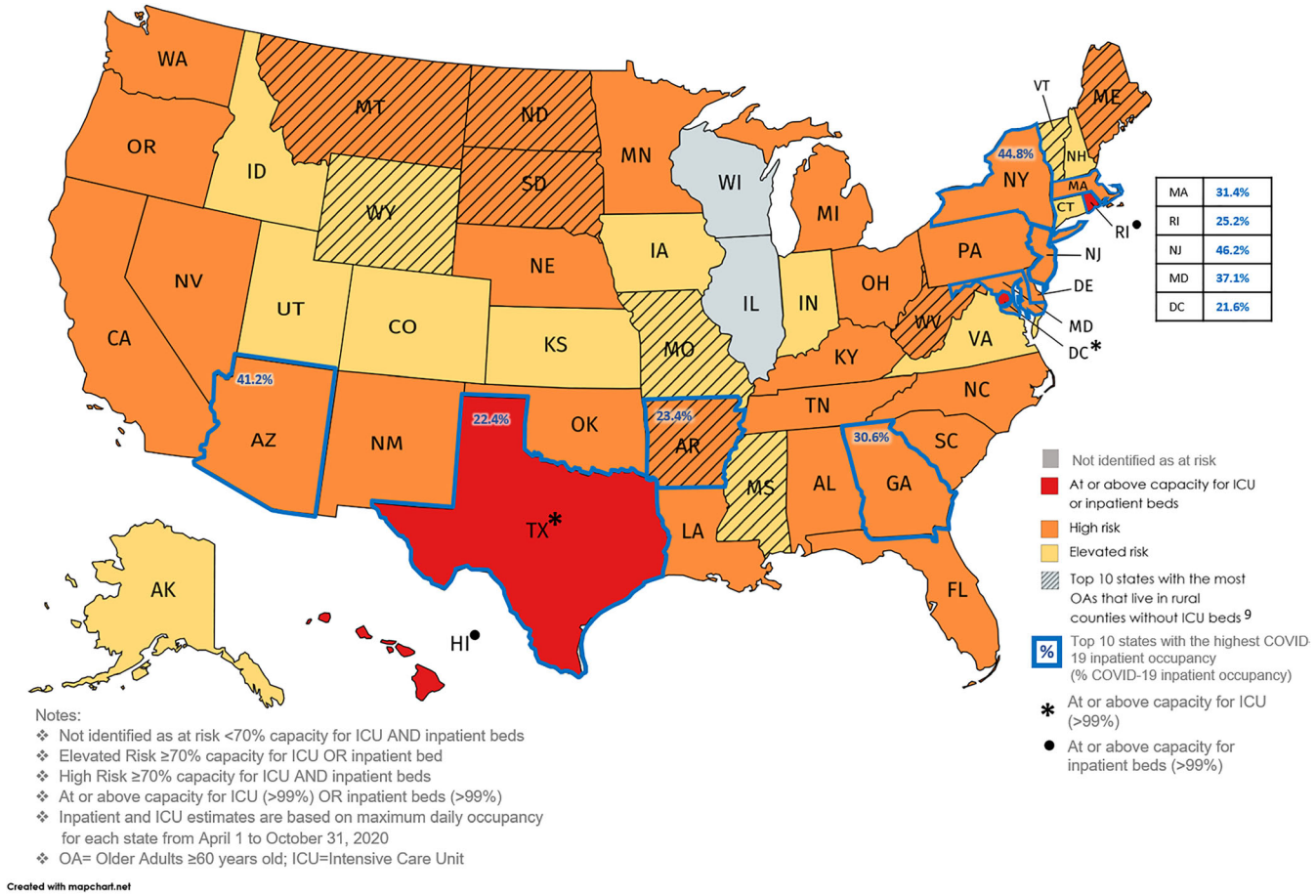

FIGURE 1 States' risk of reaching capacity and top 10 states with the highest daily burden for COVID-19 inpatient occupancy from 1 April to 31 October 2020

Over the time period, the non-COVID-19 inpatient occupancy had a significant positive linear relationship for all 6 states ($P < .001$). Rhode Island (0.20%), Maryland (0.13%), DC (0.16%), Georgia (0.11%), and South Carolina (0.11%) experienced increases higher than the national estimate of 0.09% per day in percent inpatient occupancy by non-COVID-19 patients.

4 | DISCUSSION

Our results show that hospital inpatient and ICU bed occupancy is a major concern across the United States. From 1 April to 31 October 2020, 72.5% of states and territories had reached a maximum daily inpatient occupancy of 70% or greater, and 90.2% of them had reached a maximum ICU occupancy of 70% or greater. Four of the states/territories reached at or above capacity during the time period for ICU or inpatient beds. States with the highest sustained occupancy for inpatient and ICU beds were Alabama, DC, Georgia, Maryland, Rhode Island, and South Carolina. Georgia and Maryland were not only among the states with the highest sustained inpatient and ICU occupancy but also had the highest COVID-19 inpatient occupancy. Immediate contingency planning and resource allocation are needed for states reaching capacity for either ICU or inpatient beds, which will have negative consequences on health outcomes and the healthcare system.

Based on this national data, 56 patients will be admitted inpatient and 8 patients will be admitted into the ICU for every 100 new cases of COVID-19; though these estimates were not able to be adjusted by important population characteristics, it may inform the overall burden on the healthcare system. Despite inpatient occupancy for COVID-19 declined over the time period, trends in overall occupancy did not, indicating there may be indirect consequences of the pandemic on population health outcomes from delayed access to care. Non-COVID-19 inpatient occupancy has increased nationally by 0.09% per day over the course of the epidemic ($P < .001$). States experiencing the highest COVID-19 inpatient burden also are experiencing higher rates of non-COVID-19 inpatient admissions than the national average. New Jersey and Rhode Island had the highest daily increases in non-COVID-19 admissions. Local and state healthcare systems should monitor admissions to see if they are experiencing a "double burden" on bed capacity, such as in New Jersey. New Jersey is one of the highest states for COVID-19 inpatient admissions and had the highest national increase in non-COVID-19 inpatient admissions (0.20% daily increase). In addition, states with

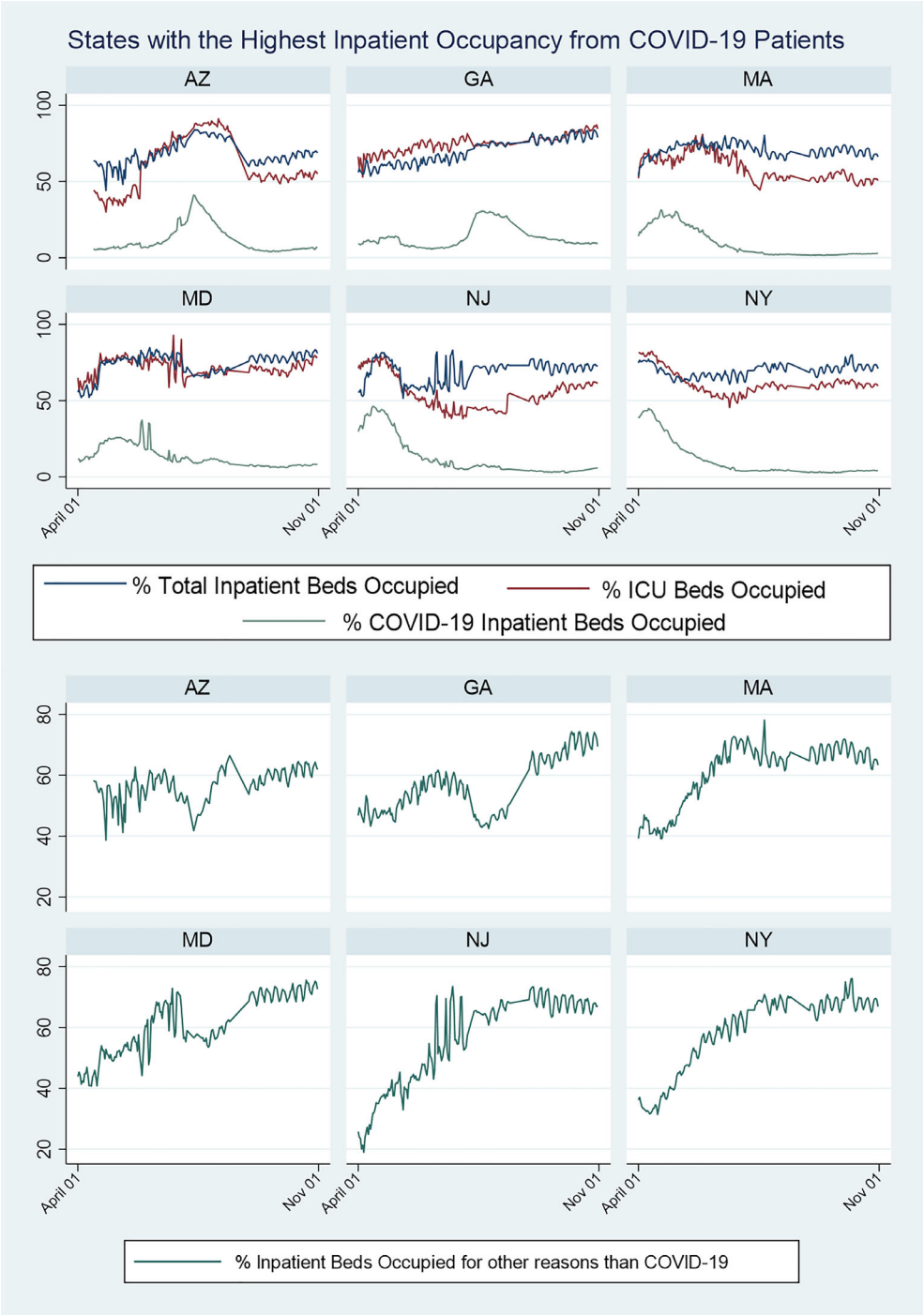

FIGURE 2 States with the highest inpatient bed occupancy from COVID-19 patients by state from 1 April to 31 October 2020

the highest inpatient COVID-19 admissions were not always the states with the highest bed occupancy overall. Rhode Island was not one of the top states with the highest COVID-19 inpatient admissions but did experience the highest daily increase for non-COVID-19 admissions in the nation with ongoing capacity issues. More research is needed to determine the reasons for admissions that are not due to COVID-19, and the added burden that these admissions will have on the healthcare system.

Research needs to determine the epidemic's impact on smaller geographic areas and those from rural communities, older adults, minorities, immigrants, low income, uninsured, and those located in federally designated health provider shortage areas and medically underserved populations/areas.[1,10,12] Many rural areas in the United States have little to no access to acute or critical care. States that have the highest population of older adults (60 years and older) that live in rural counties with no ICU bed should have special consideration,[10] especially since these states are already experiencing a high and elevated risk of reaching capacity. Special attention should be given to Arkansas because it was one of the top 10 states for COVID-19 inpatient occupancy, face large populations of older adults living in rural counties without ICU beds, and reached greater than 70% occupancy for both inpatient and ICU beds.

4.1 | Limitations

The aggregated state-level estimates limit our ability to adjust for important population characteristics in our model or identify smaller geographic areas where there are COVID-19 hotspots or that experience limited bed capacity. This study provides preliminary evidence of the state-level bed occupancy during the epidemic. Therein, states that were not identified at risk of reaching capacity may also experience capacity issues within smaller geographic areas.

5 | CONCLUSION

Even though inpatient occupancy for COVID-19 declined over the time period, trends overall for inpatient and ICU occupancy did not. Careful attention needs to be given to admissions that are non-COVID-19 related as the pandemic progresses. Further overburdening already overwhelmed healthcare facilities will likely have a negative impact on the quality of care, access to care, and health outcomes, in the short- and long-terms. As a consequence, we may expect to see increases in emergency room admissions and preventative hospitalization. The long-term impact of the overburdened healthcare system is yet to be determined but could be related to the delay of care for chronic diseases.

ETHICS STATEMENT

This research has been deemed not human subject research by U.S. Department of Health and Human Services, and uses publicly available aggregated statistics at the state level.

CONFLICT OF INTEREST

The authors have no potential conflicts of interest to declare regarding the work involved in this article.

AUTHOR CONTRIBUTIONS

Conceptualization: Kate E. Trout, Li-Wu Chen
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Formal Analysis: Kate E. Trout
Methodology: Kate E. Trout, Li-Wu Chen
Visualization: Kate E. Trout, Li-Wu Chen
Writing – Original Draft Preparation, Review, & Editing: Kate E. Trout, Li-Wu Chen

All authors have read and approved the final version of the manuscript.

Dr. Kate E. Trout had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

TRANSPARENCY STATEMENT

Dr. Kate E. Trout affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in HealthData.gov for hospital ICU and inpatient beds occupied by the state.

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