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U.S. Adult Critical Care Beds Per Capita: A 2021 County-Level Cross-Sectional Study

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IMPORTANCE: Per capita geographic distribution of adult critical care beds can be utilized for healthcare resources assessments.

OBJECTIVES: Describe the per capita distribution of staffed adult critical care beds across the United States.

DESIGN, SETTING AND PARTICIPANTS: Cross-sectional epidemiologic assessment of November 2021 hospital data from the Department of Health and Human Services' Protect Public Data Hub.

MAIN OUTCOMES AND MEASURES: Staffed adult critical care beds per adult population.

RESULTS: The percent of hospitals reporting was high and varied by state/territory (median, 98.6% of states' hospitals reporting; interquartile range [IQR], 97.8–100%). There was a total of 4,846 adult hospitals accounting for 79,876 adult critical care beds in the United States and its territories. Crudely aggregated at the national-level, this calculated to 0.31 adult critical care beds per 1,000 adults. The median crude per capita density of adult critical care beds per 1,000 adults across U.S. counties was 0.00 per 1,000 adults (county, IQR 0.00–0.25; range, 0.00–8.65). Spatially smoothed county-level estimates were obtained using Empirical Bayes and Spatial Empirical Bayes approaches, resulting in an estimated 0.18 adult critical care beds per 1,000 adults (range from both methodological estimates, 0.00–8.20). When compared to counties in the lower quartile of adult critical care bed density, counties in the upper quartile had higher average adult population counts (mean 159,000 vs 32,000 adults per county) and a choropleth map demonstrated high densities of beds in urban centers with low density across rural areas.

CONCLUSIONS AND RELEVANCE: Among U.S. counties, the density of critical care beds per capita was not uniformly distributed, with high densities concentrated in highly populated urban centers and relative scarcity in rural areas. As it is unknown what defines deficiency and surplus in terms of outcomes and costs, this descriptive report serves as an additional methodological benchmark for hypothesis-driven research in this area.

KEY WORDS: critical care; epidemiology; health services; public health; supply & distribution

The COVID-19 pandemic has underscored the importance of developing a robust and granular understanding of the availability of critical care beds (CCBs) among U.S. communities and incorporating this information into routine public health administration and policy. Robust and up-to-date epidemiological information on the distribution of resources at different levels of geographic scale and methodological aggregation are important layers for public health and healthcare systems planning. Hospital referral regions (HRRs) such as the Dartmouth Atlas of Healthcare have been used to describe the distribution of CCBs but were originally developed for tertiary healthcare, specifically

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KEY POINTS

Question: What is the per capita distribution of adult critical care beds among the U.S. adult population?

Findings: Aggregated at the national or state-level estimated 0.31 adult critical care beds per 1,000 U.S. adults. Aggregated at the county-level, the crude median of 0.00 adult critical care beds per 1,000 adults (interquartile range among counties 0.00–0.25) differed from a geographically smoothed estimate of 0.18 adult critical care beds per 1,000 adults.

Meaning: There was a wide county-level difference in the number of adult critical care beds per capita; however, further work is needed to understand how this affects treatment, costs, and outcomes.

cardiovascular and neurosurgical procedures, and may not be specific to CCB distribution (1–3). Additionally, the Pittsburgh Atlas critical care referral regions developed from Medicare claims have provided an important facet of critical care epidemiology describing where patients go to receive their critical care (4).

County-level geographic distribution of CCBs per capita may provide a complementary description of the spatial distribution of resources distinct from referral regions that can include multiple counties. Therefore, the overarching aim of this study was to describe the distribution of adult CCBs per capita among U.S. states and counties. We used both crude counts and several geographically smoothed methodologies to provide a comprehensive view of county-level CCBs and account for the fact that people can cross geopolitical boundaries to receive care. For this objective, we used a relatively newly available federal dataset from the U.S. Department of Health and Human Services (HHS) that collects up-to-date information on staffed CCBs from a high proportion of U.S. hospitals.

MATERIALS AND METHODS

Study Design and Data Sources

This is a descriptive, cross-sectional study utilizing two data sources: the HHS Protect Public Data Hub's Hospital Utilization data and the U.S. Census Bureau's American Community Survey (ACS). At the time of data extraction (November 2021), the HHS Protect Public Data Hub was receiving facility-level data points at different frequencies, up to a daily basis, from two sources: an HHS TeleTracking Network for individual healthcare facilities and from state and territorial health departments reporting on behalf of their healthcare facilities (5). The ACS is an ongoing monthly survey sent to a rolling sample of approximately 3.5 million addresses in the United States annually. In conjunction with the U.S. Census Bureau's decennial census, the ACS provides multiyear population size estimates and demographic characteristics for small geographic areas of the United States (6). We used the 2019 ACS 5-year summary estimates for this analysis, which were the most recent available data at the time. To describe the per capita density of adult CCBs among U.S. states and counties, we merged the HHS and ACS data using Federal Information Processing Standards geographic identifiers.

Participant Facilities and Variables

At the time of data extraction, the HHS data included hospitals registered with Centers for Medicare & Medicaid Services (CMS) as of June 1, 2020, and hospitals not registered with CMS but that had reported to the HHS since July 15, 2020. The hospital utilization data did not include psychiatric, rehabilitation, Indian Health Service, U.S. Department of Veterans Affairs, Defense Health Agency, or religious nonmedical facilities (5). For this project's focus on adult CCB distribution, we excluded pediatric hospitals that did not report any adult CCBs.

The primary HHS numerator variable was the "average number of total staffed inpatient adult ICU beds reported in the 7-day period (5)." While the HHS documentation does not specifically define the parameters of a CCB, it states that "all ICU beds should be considered, regardless of the unit on which the bed is housed. This includes ICU beds located in non-ICU locations, such as mixed acuity units (7)." The primary ACS denominator variable was the 5-year weighted average county population count estimates of adults greater than or equal to 18 years old. We additionally extracted ACS county- and state-level characteristics (see **eTables 1** and **2**, http://links.lww.com/CCX/B144, for full list of variables and any descriptions of variable transformations, respectively) and used the National Center for Health Statistics urban-rural classification system for counties (8).

Statistical Analyses

Our study aim was to describe the distribution of adult CCBs per capita at different levels of geographic aggregation. We hypothesized that different geographic patterns may emerge at different levels of aggregation (i.e., county vs state levels), consistent with the "modifiable area unit problem" encountered with geospatial data and unknown domain unit standards (6).

For the state- and county-level analyses, we used four different methods to estimate adult per capita CCBs: a crude count and three geospatial smoothing techniques. The crude estimates provided the location of actual (reported and unadjusted) resources within specified geopolitical boundaries. The geospatial smoothing estimates conceptually accounted for the fact that people can cross county and state borders to receive critical care. As the optimal smoothing method was unknown, we deployed three: Empirical Bayes (EB), Spatial Empirical Bayes (SEB), and the Besag-York-Mollié model using the integrated nested Laplace approximation R package (9–11). Each method applies a different statistical approach of geographic averaging of CCBs and population by borrowing strength of information from varied geographically proximal and area-level estimates (see **eMethods**, http://links.lww.com/CCX/B144, for additional description).

We compared the demographic characteristics between areas with relatively high and low CCB density, utilizing the SEB estimates to define the upper and lower quartiles of county CCB density. Given that this was nationally representative data rather than a statistical sample, we did not perform statistical inference testing on these comparisons.

This work was performed with publicly available, deidentified data and therefore did not meet Institutional Review Board criteria for human subjects research to require a review.

All data management was performed in RStudio (Version 4.1.0) using the *tidyverse* package (Version 1.3.1) (12, 13).

RESULTS

Per Capita Density of U.S. Critical Care Beds

At the national level, from the 5,072 total hospitals in the dataset at time of extraction, we excluded 608 pediatric hospitals with no reported adult CCBs. From the resultant 4,846 adult hospitals, there were a total of 79,876 adult CCBs in the United States and its territories. Aggregated at the national level, there was a crude density of 0.31 adult CCBs per 1,000 adult population. Among states, hospital reporting rates were high (median, 98.6% reporting; interquartile range [IQR], 97.8–100%) (see **eTable 3**, http://links.lww.com/CCX/B144, for full data by state/territory). Aggregated at state-level, the median crude per capita density of adult CCBs among states matched the nationally aggregated estimate of 0.31 CCBs per 1,000 adults but varied across states (states' IQR, 0.25–0.36; range, 0.17–0.55) (**eTable 4**, http://links.lww.com/CCX/B144). The average median per capita density from two geographically smoothed estimates (EB and SEB) at the state-level remained at 0.31 CCBs per 1,000 adults (suggesting the results were well-calibrated to the national level). The average lower and upper quartiles of the state-level smoothed estimates were 0.25 and 0.36 CCBs per 1,000 adults. Tennessee and Indiana were the states with the highest population density of adult CCBs compared to the nation (relative densities 1.4; 0.4 CCBs per 1,000 adults) behind Washington, DC (relative density 1.7; 0.5 CCBs per 1,000 adults). Rhode Island had the lowest population density of adult CCBs (relative density 0.5; 0.2 CCBs per 1,000 adults) (see **eTable 5**, http://links.lww.com/CCX/B144, for detailed list of states and territories).

Aggregated at the county-level, the median crude per capita density of adult CCBs was 0.00 per 1,000 adults (county IQR, 0.00–0.25; range, 0.00–8.65), revealing that over half of U.S. counties did not have within-county staffed adult CCBs. Visual examination of county-specific distribution of crude per capita CCBs across the continental United States demonstrated clustering of CCBs in areas of high population density and scarcity of CCBs across rural parts of the country (**Fig. 1**). However, visual examination of a scatterplot of counties' adult CCB counts by population additionally demonstrated that this pattern of larger numbers of CCBs distributed to the most populated counties was not always followed with numerous outliers of relatively high counts of adult CCBs in counties of relatively low adult population counts (**Fig. 2**). Finally, visual examination of violin plots of the distribution of counties' CCB per capita density by U.S. Census Region demonstrated that this pattern of a large upward skew, indicating outliers with higher CCB per capita density than

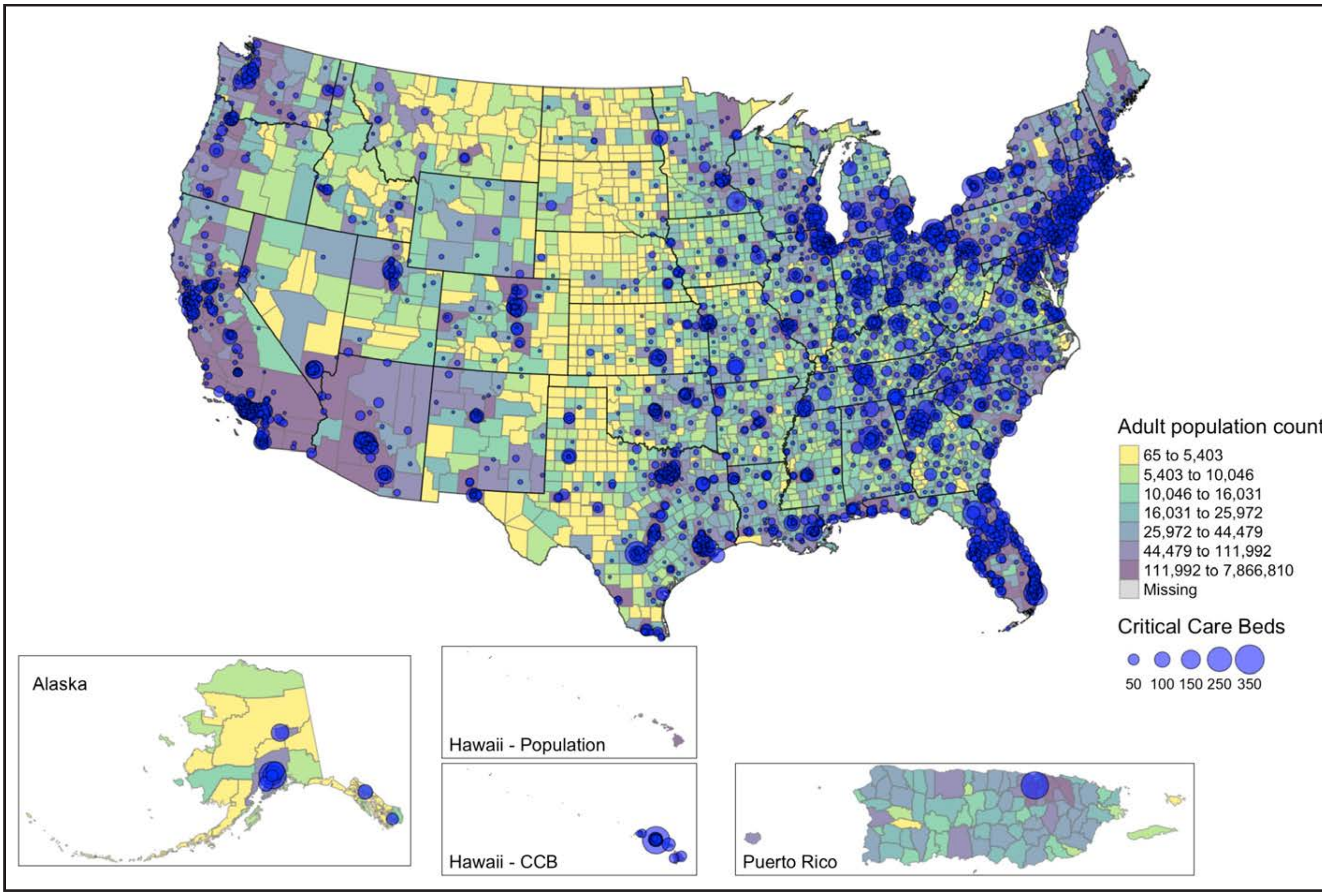

Figure 1. U.S. choropleth map of adult critical care beds (CCBs) by adult population counts. In this map, areas are defined by county borders which are colored according to estimated adult population. *Blue dots* are the locations of hospitals reporting adult CCBs, sized according to the number of CCBs reported.

the majority of counties in the area, was present in each region (**Fig. 3**). The average median per capita density from the different geographically smoothed estimates was 0.18 CCBs per 1,000 adults (range from both EB and SEB estimates 0.00–8.20). The average lower and upper quartiles of the county-level smoothed estimates were 0.10 and 0.29 CCBs per 1,000 adults (**eTable 6**, http://links.lww.com/CCX/B144).

Comparison of County Characteristics by Adult per Capita Critical Care Bed Density

Utilizing estimates from the geographic smoothing methods, we defined populated counties as "low CCB counties" if they were below the national 25th percentile of 0.11 and as "high CCB counties" if they were above the 75th percentile of 0.27 CCBs per 1,000 adults. An estimated 128 (50%) and 25 (10%) million adults lived in high and low CCB counties, respectively. When compared with low CCB counties, high CCB counties had larger adult population sizes, a higher proportion of racial minorities, a higher proportion of people living in multiunit housing, a lower proportion of people living in owner-occupied housing, and a lower proportion of people living in mobile homes. The majority of low CCB counties were rural (57% with a "non-core" or "micropolitan" designation). While the high CCB counties had the highest proportion of urban counties (6% designated as "large central metropolitan" compared with 0% among low CCB counties), they also had a large proportion of rural counties (49% with the "non-core" or "micropolitan" designation). County characteristics similar between high and low CCB counties included the proportion of population over 65 years old, proportion of Hispanic ethnicity, median household income, income disparity, proportion of population below poverty level, proportion of population without health insurance, proportion of population with at least high school diploma, and proportion

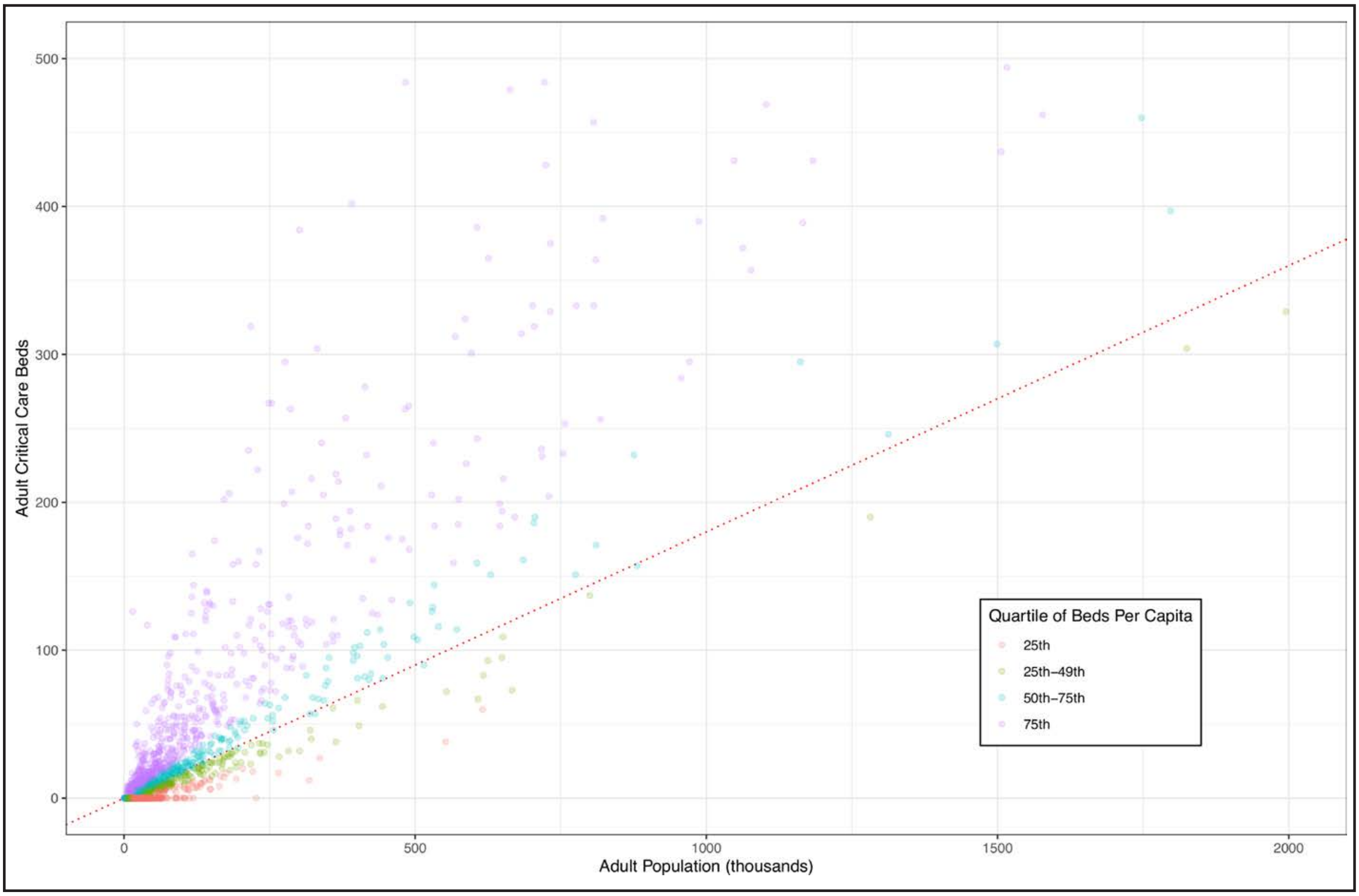

Figure 2. The number of adult critical care beds by adult population among U.S. counties. In this figure, each point represents a U.S. county. Points are color coded by which quartile of adult critical care bed per capita density they are in. The *dotted line* represents 0.18 adult critical care beds per 1,000 adults, the national median of counties' estimates estimated using geographical smoothing techniques. The *y*- and *x*-axes were limited for purposes of scaling to visualize most of the data, which excludes 19 counties (1%) from the graph.

of population unemployed (see **eTable 7**, http://links.lww.com/CCX/B144, for all county characteristics across all quartiles).

DISCUSSION

In this article, we present current data and a complementary methodological approaches to provide insights into the distribution of adult CCBs per capita across the United States. Crude calculations aggregated at the national and state levels produced an estimate of 0.31 adult CCBs per 1,000 adult population that was uniformly distributed across states. At the county-level, using geospatial smoothing techniques, the national median of counties' CCB density was attenuated to 0.18 with a skewed distribution of high CCB density outlier counties among each U.S. Census Region. Finally, our analysis and choropleth map of the continental United States demonstrated that CCBs were densely concentrated in highly populated urban areas of the country and scarce across large swaths of rural United States. This was consistent with our estimation that 50% of U.S. adults live in counties comprising the highest quartile of adult CCB per capita density.

This study used a relatively newer dataset to examine U.S. CCBs, which have been previously examined using CMS's Healthcare Cost Report Information System (HCRIS) and the American Hospital Association's (AHA) Annual Hospital Survey. Each of these three datasets has different methods of acquiring data, frequencies of data collection, and apply different bed type categorizations (**Table 1**). We chose the HHS dataset given its high level of hospital reporting, availability of recently collected data, and weekly data collection frequency. Additionally, HHS data represent the number of recently "staffed" CCBs which may better reflect the CCBs that are available to actively serve patients (14).

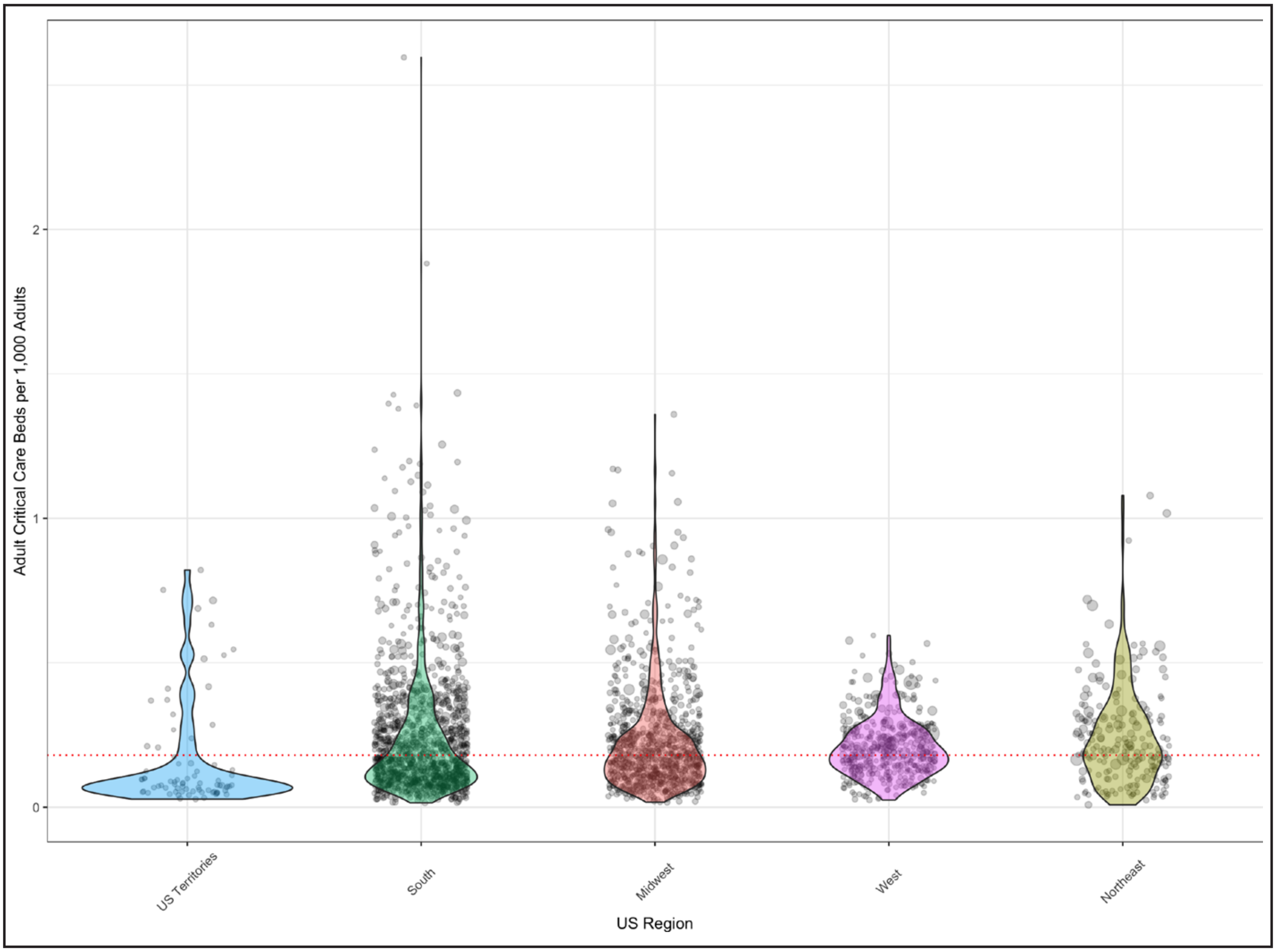

Figure 3. Distribution of county-level adult critical care beds per capita among U.S. Census Regions. In this figure, each point represents a county grouped into the U.S. Census Region in which they are located. Random variation in lateral location of points and color of each region's violin plot is applied for visualization. The number of adult critical care beds per capita represented on *y*-axis is a geographically smoothed estimate using the Empirical Bayes method. The *horizontal dotted red line* is at 0.3 adult critical care beds per 1,000 adults, the crude national average. In this plot, we omitted one extreme outlier of Montour County, Pennsylvania with eight adult critical care beds per 1,000 adults.

One of the added values of our study to this body of literature is the county-level granularity. This has conceptual validity in describing local access to resources for emergent critical illness, methodological advantages in facilitating merges with Census population characteristics, and practical importance in that some policy decisions are driven at the county-level. In comparison, a 2015 study of HCRIS data used the Dartmouth Atlas HRRs as the smallest geographic level of description (2). The 306 Dartmouth HRRs were developed to represent referral networks for tertiary healthcare, specifically cardiovascular and neurosurgical procedures, rather than emergent critical care (3). Another important study used 2011 Medicare claims data for acute myocardial infarction, stroke, and trauma to develop the novel Pittsburgh Atlas, delineating 326 critical care referral regions that by design do not cross state lines (4). That work used data of where people live and receive care to describe referral regions which comprise an important facet the concept of accessibility both for describing and organizing the regionalization of care. Our description of per capita CCB density based on spatially smoothed estimates from adjacent counties provides another complementary layer to describing local accessibility distinct from critical care referral networks that sometimes aggregate large numbers of counties across large distances.

TABLE 1.
Comparison of National Critical Care Bed Dataset

Dataset Characteristic	Health and Human Services Protect Data Hub	Healthcare Cost Reporting Information System	American Hospital Association Survey
Data collection method	Hospitals or their representative are requested to report through tele-tracking network	Medicare-certified hospitals are required to submit annual cost report including facility-level information	Voluntary survey
Data collection frequency	Daily	Quarterly	Annually
ICU bed subtypes reported[a]	Adult Pediatric	Intensive Coronary Burn Surgical Psychiatric Pediatric Neonatal Detoxification Premature	Medical-surgical Cardiac Neonatal Pediatric Burn Other

[a]The names of the ICU bed types reflect the terms used by each data source.

Another added value of this work is in our application of geospatial smoothing techniques. While smoothing techniques can be used to stabilize population estimates derived from samples, in this study with a very high level of hospital reporting, we primarily used them to produce estimates more closely aligned with our theoretical framework that populations cross political boundaries to receive care (4). While crude estimates have face and administrative validity for determining the numbers of CCBs within relevant geopolitical boundaries (2, 15, 16), we posited that it is not as robust a measure of per capita spatial distribution since prior studies have demonstrated that populations cross county lines for critical care services (4). Therefore, geospatial techniques that "average" the spatial distribution of populations and resources with nearby neighbors across geopolitical boundaries may more likely to represent the available distribution of local resources.

Our analyses demonstrated notable differences between the crude and geospatially smoothed estimates at the county-level. Specifically, the median and IQR of the crude estimate of county-level adult CCB density (0.00 and 0.00–0.25, respectively) were quite different from the values from the EB (median, 0.17; IQR, 0.11–0.27) and SEB (median, 0.19; IQR, 0.09–0.20) methodologies. From the crude estimates, one may have concluded that adults in at least 50% of U.S. counties have no local access to nearby CCBs. However, when using geospatial statistical techniques, we observed that distribution, while still skewed, is more uniformly distributed and that an estimated 50% of the adult population lives in counties in the highest quartile of CCB per capita density.

There are limitations to consider when interpreting these results. First, similar to both HCRIS and AHA, the HHS data are self-reported by facilities and the accuracy of bed counts is unknown (12). Additionally, the HHS data documentation does not provide a description of what defines a CCB, which is relevant considering that the definition of a CCB likely differs across the country. Along these lines, while the HHS dataset has distinct fields for adult and pediatric CCBs, it does not distinguish subtypes of CCBs or intermediate care beds. The AHA and HCRIS datasets each have differing sets of CCB subtype categories (Table 1), the distinction of which still relies on self-reporting (12). While neither AHA or HCRIS have a specific field for intermediate care beds, the AHA has an "Other Special Care" CCB field that allows hospitals to report bed numbers and supply a text field for description. In our experience, this can include terms such as “intermediate” or “step-down” along with other descriptions of CCB subtypes.

The differences between the HHS, HCRIS, and AHA bed classifications highlight that direct comparisons of these data sources have methodological challenges. A review reported the 2010 national tallies of adult CCBs from HCRIS and AHA at 81,477 and 87,592, respectively (summed from CCB bed types in their published table) (12). Another study using HCRIS data reported a 2009 national CCB count at 77,809 (2). While we can only speculate as to the reasons for the differences between the two HCRIS estimates 1 year apart, it may, in part, be due to different inclusion strategies of CCB subtypes and pediatric CCBs in the total sums. An earlier version of our present project used 2019 AHA data and tallied 66,366 adult CCBs with a 74% response rate to the CCB survey items (unpublished). While the HHS provides robust, up-to-date estimates, we recognize that there is a critical need for future work to directly compare concurrent estimates between HHS, AHA, and HCRIS data despite the challenges of each system using different subtype categorizations of CCBs, collecting at different frequencies, and with different response rates. Additionally, HHS’ weekly reporting frequency also opens a future line of inquiry into how this measure may vary over different spans of time.

Another limitation of the HHS dataset is that it does not include Veteran’s Affairs (VA) Hospitals in its reporting network. This is a limitation of the HCRIS data as well but not the AHA data. While VA Hospitals are a vital part of the nation’s healthcare system, their absence from the HHS data as a limitation for our objective may be tempered by two issues. First, there are 171 VA hospitals in the country. Conservatively assuming every one of these hospitals has CCBs, this would comprise 3% of 4,846 hospitals with CCBs in the HHS dataset. Additionally, the care triage networks regarding emergency care of non-Veterans at VA hospitals is likely complicated and may not represent CCBs routinely available to the public. This does highlight the need for analogous work to be done describing critical care resources for the U.S. Veteran population.

Finally, CCBs comprise only one aspect of the larger concept of critical care resources. Emergency medical services and emergency rooms are interdependent components to the chain of critical care delivery. Furthermore, a more complete description of resources would include the equipment of modern-day critical care such as functioning ventilators, high-flow oxygenation devices, and renal replacement machinery, as well as the physicians, nurses, respiratory therapists, and pharmacists. To our knowledge, there is not yet a comprehensive national dataset including all these elements.

CONCLUSIONS

These data and analyses are descriptive but informative. While the data describe the distribution of adult CCBs across the United States, they cannot tell us the specific criteria of “deficiency” or “surplus.” In many ways, we intended the work to raise more questions than provide answers and to drive further work to compare results from different datasets, different aggregations such as the Pittsburgh and Dartmouth Atlases, and over time.

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All authors contributed to the study design, interpretation, and revision of final article. Dr. Kempker drafted the entire article. Ms. Stearns performed all statistical analyses. Drs. Peterson and Waller contributed analytic oversight for all geospatial techniques and data presentations.

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