Clinical Infectious Diseases
MAJOR ARTICLE

The Disproportionate Impact of Coronavirus Disease 2019 (COVID-19) Pandemic on Healthcare-Associated Infections in Community Hospitals: Need for Expanding the Infectious Disease Workforce

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Background. The coronavirus disease 2019 (COVID-19) pandemic had a considerable impact on US healthcare systems, straining hospital resources, staff, and operations. However, a comprehensive assessment of the impact on healthcare-associated infections (HAIs) across different hospitals with varying level of infectious disease (ID) physician expertise, resources, and infrastructure is lacking.

Methods. This retrospective longitudinal multicenter cohort study included central-line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), *Clostridioides difficile* infections (CDIs), and ventilator-associated events (VAEs) from 53 hospitals (academic and community) in Southeastern United States from 1 January 2018 to 31 March 2021. Segmented negative binomial regression generalized estimating equations models estimated changes in monthly incidence rates in the baseline (01/2018–02/2020) compared to the pandemic period (03/2020–03/2021, further divided into three pandemic phases).

Results. CLABSIs and VAEs increased by 24% and 34%, respectively, during the pandemic period. VAEs increased in all phases of the pandemic, while CLABSIs increased in later phases of the pandemic. CDI trend increased by 4.2% per month in the pandemic period. On stratifying the analysis by hospital characteristics, the impact of the pandemic on healthcare-associated infections was more significant in smaller sized and community hospitals. CAUTIs did not change significantly during the pandemic across all hospital types.

Conclusions. CLABSIs, VAEs, and CDIs increased significantly during the pandemic, especially in smaller community hospitals, most of which lack ID physician expertise. Future efforts should focus on better understanding challenges faced by community hospitals, strengthening the infection prevention infrastructure, and expanding the ID workforce, particularly to community hospitals.

Keywords. SARS-COV-2; CLABSIs; CAUTI; *C. difficile*; VAE.

Healthcare-associated infections (HAIs) are key quality and safety indicators for US acute care hospitals. HAI rates are publicly reported and impact hospital reimbursement by the Centers for Medicare and Medicaid Services (CMS) [1]. National efforts led to reduction of central line associated bloodstream infection (CLABSI), catheter-associated urinary tract infection (CAUTI), *Clostridioides difficile* infections (CDIs), and ventilator associated events (VAEs) over the past decade [2].

The coronavirus disease 2019 (COVID-19) pandemic had a considerable impact on US healthcare systems, straining hospital resources, staff, and operations, and further exacerbated the shortage of infectious disease (ID) physicians [3–7]. Nearly two-thirds of all Americans are primarily served by community hospitals and live in counties with a below-average density of ID physicians or no ID physician access [8]. Even before the pandemic, surveys highlighted that less than a quarter of community hospitals had ID specialists on staff, of which only a minority received training in in hospital epidemiology and

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infection prevention [9]. Robust evidence supports the association between ID physician intervention and improved outcomes [10].

By early December 2020, COVID-19 hospitalizations accounted for about 15% of occupied inpatient beds [11]. Patients with COVID-19 required higher acuity of care with more diagnostic, therapeutic, and safety measures, which placed tremendous pressure on healthcare workers, from staffing challenges to risk of exposure and infection [4, 12–14]. In addition, there was a precipitous drop in elective surgical cases, and a decline in admissions for other medical conditions, resulting in a higher case mix index among hospitalized patient populations [11]. Furthermore, COVID-19 patients needed close monitoring and higher levels of care, including ventilatory and critical care support [15–17]. In summary, hospitals faced dynamic and critical challenges to healthcare delivery during each pandemic surge.

Prior data from other health systems and national surveillance provided some insights on the impact of the COVID-19 pandemic on HAIs [3, 5, 18]. However, these data did not assess impact across hospitals of different types (academic vs community), were limited to assessment of early pandemic timelines, and did not explore effects in different phases of the pandemic. Our objective was to evaluate the impact of COVID-19 pandemic on incidence and trends of HAIs in a large network of academic and community hospitals across different phases of the pandemic, and better understand the impact on under-resourced community hospitals.

Study Design

We performed a retrospective, longitudinal study of CLABSIs, CAUTIs, CDIs, and VAEs in a large network of hospitals from 1 January 2018 to 31 March 2021. The study included a "baseline period" from 1 January 2018 – 29 February 2020 and "pandemic period" from 1 March 2020 to 31 March 2021. The "pandemic period" was further divided into 3 "pandemic phases" in order to match COVID-19 surge patterns observed in study sites: Pandemic Phase 1 (03/2020–06/2020), Pandemic Phase 2 (07/2020–10/2020), and Pandemic Phase 3 (11/2020–3/2021) as shown in Figure 1.

Setting

This study included data from 53 hospitals, which included 2 large academic medical centers: Duke University Hospital, an acute-care, academic, tertiary-care facility in Durham, North Carolina, and the University of North Carolina Medical Center, an academic medical center in Chapel Hill, North Carolina, and 51 community hospitals in the Duke Infection Control Outreach Network (DICON) in the southeastern United States [19].

Definitions

CLABSI, CAUTI, CDIs, and VAEs were defined based on Centers for Disease Control and Prevention's (CDC's) National Health Safety Network (NHSN) surveillance definitions [20]. There were no major HAI definition changes during the study period. Hospital characteristics included hospital type and size. Hospitals were categorized by type into academic medical centers and community hospitals, and stratified by size into large (≥425 beds), medium (250–424 beds), and small (≤249 beds) hospitals, based on the Agency for Healthcare Research and Quality's Healthcare Cost and Utilization Project National Inpatient Sample Description of Data Elements [21]. Pandemic phases were defined based on COVID-19 case burden (using COVID19 admissions), representing the strain on the hospital resources and frontline workers (Figure 1). COVID-19 admission was defined as an inpatient hospitalization with an ICD10 diagnosis code of U07.1 (after April 2020) or B97.29 (March 2020–April 2020). COVID-19 admissions were assigned to the month of the admission date.

Data Collection

The study design was approved by the institutional review board of Duke University Health System (Pro00107094). Informed consent for data collection was waived because all relevant epidemiologic data were abstracted by each participating site without transfer of any protected health information. Trained infection preventionists at each hospital collected surveillance data using a standardized database and NHSN definitions. DICON liaison infection preventionists validated a subset of surveillance data each month. The study database included variables measured per hospital-month on the facility-wide level. The outcomes were reported as CLABSIs per 1000 central catheter days, CAUTIs per 1000 urinary catheter days, CDI per 10 000 CDI patient days, and VAE per 1000 ventilator days. Secondary outcomes included central catheter days, urinary catheter days, and ventilator days. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Analysis

Outcomes were reported descriptively as mean (standard deviation [SD]) hospital-level monthly incidence rates (IR) by period—"baseline period," "pandemic period," or "pandemic phases." Mean hospital-level monthly IR and device days were compared using negative binomial regression GEE models with period as the only covariate. Segmented regression (SR) analyses using generalized estimating equations (GEE) models were performed to estimate changes in monthly IR of CAUTIs, CLABSIs, CDIs, and VAEs. Poisson distribution was assumed for VAE, and negative binomial distribution was assumed for all other HAIs. The working correlation matrix assumption

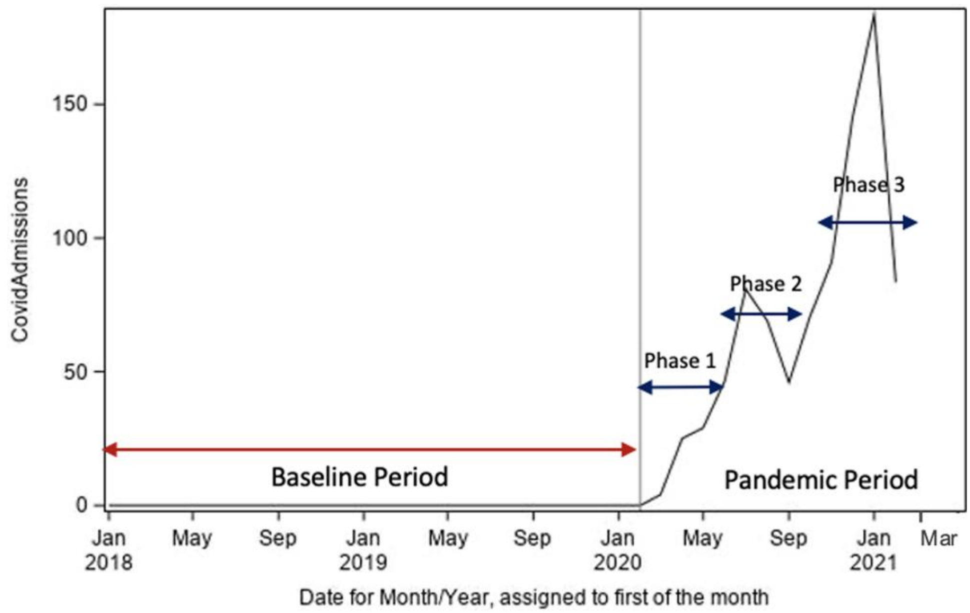

Figure 1. Trend of COVID-19 admissions over baseline (1 January 2018 to 29 February 2020) and pandemic period (1 March 2020 to 31 March 2021) (stratified into 3 pandemic phases). Abbreviation: COVID-19, coronavirus disease 2019.

was compound symmetry for CLABSI, CDI, and VAE, and independent for CAUTI models. Unit of analysis was hospital-month. The data were analyzed in the following ways to provide summary estimates of interest and then to adjust for hospital characteristics (type and size) and COVID-19 pandemic phases:

1. Pre- and post-comparison of HAI IRs and device days in baseline and entire pandemic period.
2. Unadjusted analysis showing overall trends of HAIs in baseline and pandemic periods: All models included variables for time since the beginning of the observation period (starting 12/2017), time since the beginning of the pandemic (starting 03/2020), and type of period (baseline vs the pandemic).
3. Unadjusted analysis showing HAI trends in baseline and pandemic period stratified by hospital type and size: Stratified analyses included subgroup variable for hospital type (academic vs community), or hospital size (small, medium, or large), and interactions between subgroup and all other variables in the model.
4. Analysis adjusted for hospital characteristics showing HAI trends in baseline period and three pandemic phases to evaluate the impact of different pandemic phases on infection trends: All models included variables for time since the beginning of the observation period (starting 12/2017), pandemic phases (baseline period, pandemic phase 1, 2, or 3), time since the beginning of each pandemic phase, number of hospital beds, hospital type (academic vs community).

All statistical tests were 2-sided with alpha level of 0.05. All analyses were performed using SAS v.9.4 (SAS Institute, Cary, North Carolina, USA).

RESULTS

In our large network of 53 hospitals over a 39-month study period, there were 4060 COVID-19 admissions in pandemic phase 1, 9593 COVID-19 admissions in pandemic phase 2, and 17 586 COVID-19 admissions in pandemic phase 3 (Figure 1).

Hospital Characteristics

The 2 large academic medical centers included in the study have 803 and 957 beds, whereas the community hospitals range in size from 38 to 721 beds (median, 162 beds) in 6 states: North Carolina, South Carolina, Virginia, Florida, Georgia, and West Virginia [19]. Thirty-nine community hospitals were classified as small in size, whereas 12 community hospitals were medium and large. Seventy five percent of our community hospitals are located in counties without an ID physician, or in counties where ID physician density is lower than national average (1.76 per 100 000 US population, Supplementary Figure 1) [8].

Pre and Post Comparison of HAI Incidence Rates and Device Days in Baseline and Pandemic Period

Mean monthly CLABSI IR increased significantly from 0.6 to 0.9 per 1000 catheter days ($P = .0023$), whereas VAE IR increased from 6.1 to 10.9 per 1000 ventilator days ($P < .001$) during the entire pandemic period. In contrast, CAUTI IRs ($P = .81$) did not change significantly during the pandemic (see Supplementary Table 1). Overall mean monthly CDI IR decreased significantly from 3.6 to 2.6 per 10 000 patient-days in the pandemic period ($P < .001$). Compared to baseline period, mean central line days (937 vs 969, $P = .033$) and mean ventilator days (210 vs 281, $P < .001$) increased, but mean urinary catheter days (798 vs 817, $P = .16$) or mean CDI patient-days (4877 vs 4765, $P = .21$) remained unchanged during the pandemic period.

Unadjusted Analysis Examining HAI Trends in Baseline and Pandemic Periods

In the unadjusted analysis, CLABSI and VAE trends were stable in the baseline period. However, CLABSI and VAE IRs increased by 24% (95% confidence interval [CI]: 1.2–51.4%, $P = .038$) and 34% (95% CI: 7–67.8%, $P = .011$), respectively, at the start of the pandemic period (Supplementary Figure 2, Table 1: "Pandemic Level Change"). CDI IR was decreasing by 2.1% per month during the baseline period (95% CI: s−1.1% to −3.1%, $P < .001$) but increased by 4.2% per month in the pandemic period (95% CI: 1.7–6.8%, $P = .001$; Table 1: "Pandemic Trend Change"). CAUTI IR did not change significantly during the baseline and pandemic periods. (Supplementary Figure 2, Table 1: "Pandemic Level and Trend Changes").

Analysis Examining HAI Trends Further Stratified by Hospital Type and Size

On stratifying the analysis by hospital type, CLABSI and VAE IRs increased significantly in community hospitals by 48% and 41.4% respectively but did not change significantly in academic hospitals at the start of the pandemic (Supplementary Table 2). CDI IR increased by 4.5% per month in community hospitals during the pandemic period but decreased by 43% at the start of the pandemic period in academic hospitals (Supplementary Table 2). CAUTI trends remained unchanged across all hospital types in the pandemic period (Supplementary Table 2). However, the differences between academic and community hospitals were not statistically significant (interaction P values > .05).

On stratifying the analysis by hospital size, CLABSI IR increased by 82.1% across small hospitals at the start of the pandemic and by 6.3% per month across medium sized hospitals (Supplementary Table 3). VAE IR increased by 48.7% and 104% across small and medium sized hospitals respectively, at the start of the pandemic (Supplementary Table 3). CLABSI and VAE IRs remained relatively stable in large hospitals during the pandemic. CDIs increased in small and medium hospitals by 4.5% and 12.5% per month. On the contrary, CDI IR decreased in large hospitals by 27% at the start of the pandemic (Supplementary Table 3). Pandemic level changes for CLABSI IR (interaction P value = .024), and baseline trend changes for CDI and CAUTI IR (interaction P values .042 and .023, respectively) were significantly different by hospital size.

Analysis Examining HAI Trends Adjusted for Hospital Characteristics in Baseline and Pandemic Phases

After adjusting for hospital characteristics and including pandemic phases, VAE IR increased significantly in all three pandemic phases: 33.9% (95% CI: 4.5–71.4%, $P = .020$) in phase 1; 42.9% (95% CI: .3–103.5%, $P = .048$) in phase 2, and 53.3% (95% CI: 12.3–109.4%, $P = .007$) in phase 3 (Figure 2, Table 1: "Pandemic Level Change") compared to baseline period. VAE IR trend started to decline in pandemic phase 3 (−7.3%, (95% CI: −12.3% to −2.0%, $P = .007$). CLABSI IR was stable in pandemic phase 1 but increased by 44.3% at the start of pandemic phase 2 (95% CI: 6–96.2%, $P = .019$) and 48.7% at the start of pandemic phase 3 (95% CI: 9.5–102%, $P = .011$) compared to the baseline period. CDI and CAUTIs IRs did not change significantly during any pandemic phases (Figure 2, Table 1: "Pandemic Level and Trend Changes").

DISCUSSION

In this large multistate cohort of hospitals, overall rates of CLABSIs, CDIs, and VAEs increased significantly during the COVID-19 pandemic. In contrast, we observed no change in CAUTI rates during the pandemic. Furthermore, VAE rates increased across all phases of the pandemic, whereas CLABSIs increased during later phases of the pandemic. Our data also highlight that the COVID-19 pandemic exerted a disproportionately larger impact on smaller community hospitals compared to large academic medical systems.

To the best of our knowledge, our study is the first to addresses disparities among larger academic hospitals and smaller community hospitals with respect to HAI trends during the pandemic. The differences in impact of the COVID-19 pandemic across hospital types could be secondary to differences in resource allocation, availability of ID expertise, and catchment area served by smaller community hospitals [22]. Despite access to remote infection prevention expertise through DICON, these community hospitals struggled to manage complex COVID-19 patients, to advocate for resources, staff, and infrastructure, and retain focus on patient safety in the absence of an onsite ID physician champion [23–25]. Additionally, most of the smaller community hospitals in our network are located in rural areas [19] and primarily cater to an underinsured older population with several comorbidities [26]. Furthermore, these hospitals struggled with staffing shortages, financial challenges, and operational limitations for years, only to be exacerbated by the pandemic [9, 27]. Even prior to the pandemic, 172 rural hospitals closed according to the North Carolina Rural Health Research Program [28]. During the pandemic, the volume and acuity of COVID-19 cases quickly overwhelmed the very limited resources in community hospitals in these areas [12].

Our analysis also highlights changes in HAI trends during different phases of the pandemic: VAE rates increased across all phases of the pandemic, although CLABSIs increased during later phases of the pandemic. Furthermore, our survey data from early and late stages in the pandemic suggest that specific

Table 1. **Impact of COVID-19 Pandemic on Incidence Rates of CLABSIs, CAUTIs, VAE, and CDIs**

Unadjusted Segmented Regression Analysis Showing Level and Trend Changes for Baseline and Pandemic Period

	Baseline Trend RR (95% CI)	Pandemic Level Change RR (95% CI)	Pandemic Trend Change RR (95% CI)
CLABSI	0.996 (.989–1.003)	**1.238[a] (1.012–1.514)**	1.017 (.993–1.042)
CAUTI	1.001 (.991–1.011)	1.030 (.857–1.238)	0.997 (.97–1.024)
VAE	1.007 (.991–1.022)	**1.340[a] (1.07–1.678)**	0.997 (.976–1.018)
CDI	**0.979[a] (.969–0.989)**	0.863[a] (.742–1.004)	**1.042[a] (1.017–1.068)**

Segmented Regression Analysis Adjusted for Hospital Characteristics (Type and Size) Showing Trends for Baseline Period and Pandemic Phases 1, 2, and 3

		Pandemic Phase 1		Pandemic Phase 2		Pandemic Phase 3	
	Baseline Trend RR (95% CI)	Level Change RR (95% CI)	Trend Change RR (95% CI)	Level Change RR (95% CI)	Trend Change RR (95% CI)	Level Change RR (95% CI)	Trend Change RR (95% CI)
CLABSI	0.996 (.989–1.003)	0.955 (.732–1.246)	1.162 (.993–1.361)	**1.443[a] (1.060–1.962)**	1.001 (.906–1.105)	**1.487[a] (1.095–2.020)**	0.975 (.899–1.057)
CAUTI	1.001 (.991–1.011)	1.086 (.79–1.494)	0.862 (.721–1.032)	1.195 (.881–1.621)	0.998 (.831–1.198)	1.145(.794–1.653)	0.913 (.808–1.031)
VAE	1.007 (.991–*1.023)	**1.339[a] (1.045–1.714)**	0.972 (.874–1.081)	**1.429[a] (1.003–2.035)**	0.936 (.854–1.027)	**1.533[a] (1.123–2.094)**	**0.927[a] (.877–.980)**
CDI	**0.977[a] (.967–0.987)**	0.956 (.719–1.270)	1.061 (.926–1.215)	0.912 (.715–1.164)	1.032 (.906–1.174)	1.29 (.998–1.669)	1.068 (.990–1.151)

Abbreviations: CAUTI, catheter-associated urinary tract infections; CDI, *C. difficile* infections; CI, confidence interval; CLABSI, central-line-associated bloodstream infections; COVID-19, coronavirus disease 2019; RR, rate ratio; VAE, ventilator-associated events.

[a]**Statistically significant.**

risk factors were more prominent during different phases of the pandemic [4, 12]. Our initial survey highlighted resource shortages, use of contingency strategies, decrease in elective procedures, and inconsistencies in protocols early in the pandemic [12]. Additionally, in-person patient care was primarily performed only by essential team members, while other staff and consultants performed "electronic medical record rounding" [29]. Intravenous pumps were placed in hallways to avoid frequent re-entry of nurses to rooms of patients infected with COVID-19 [30]. These changes in workflow likely led to lapses in insertion and maintenance practices, and delayed removal of devices. Later in the pandemic, elective procedures were restarted, testing capacity increased, and resource shortages improved. However, the increasing COVID-19 burden exacerbated staff fatigue, staffing shortages, and led to increase in resignations, which further adversely impact patient care [4, 31]. In addition, hospitals attempted to mitigate staffing issues by recruiting travelling nurses or reassignment of infection prevention and antibiotic stewardship staff to cover other critical duties [4, 32], likely further contributing to lapses in infection prevention and antibiotic stewardship [15].

Interestingly, CAUTI rates remained unchanged during the pandemic in our network of hospitals. This is possibly, in part, due to lack of change in urinary catheter use during the pandemic, and partly due to the limitations of the NHSN CAUTI definition [21]. We hypothesize that there may have been an increase in culture negative CAUTIs (not captured by current NHSN definition), as many COVID-19 patients were receiving antimicrobials [33] at the time of urine culture collection likely leading to sterilization of urine. There may have also been a shift in testing practices from overuse of urine cultures to focusing on repeat SARS-COV-2 testing for febrile episodes in critically ill patients [34].

Several health systems reported an increase in CLABSIs during the COVID-19 pandemic [3, 5]. However, there were mixed results in trends of CAUTIs and CDIs, and limited data on VAEs [5]. These mixed results can partly be explained by design of the study, for example, comparing time-trended analysis with pre-post comparisons. Additionally, prior studies were also limited by shorter time periods of analysis, and lack of adjustment for COVID-19 burden and hospital characteristics [3, 5, 18]. In contrast, our data account for over 3 years of trended infection data, includes pandemic phases based on COVID-19 burden and accounts for the differential impact on under-resourced hospitals that lack ID expertise. Additionally, our analysis of the impact of COVID-19 on antibiotic use and surgical site infections has been previously reported [35, 36]. Overall, we believe our methodological improvements have led to novel insights on the impact of the COVID-19 pandemic on HAIs.

Our study has limitations. HAI outcomes were based on the use of surveillance definitions. However, surveillance methods were applied systematically across all network hospitals throughout the pandemic. We only included data until March 2021. However, our study reports over 3 years of longitudinal data. We did not include microbiology data, specific data on ID physicians, and severity of illness in this analysis, as our goal was to evaluate the overall impact of pandemic phases and hospital characteristics. Although we have adjusted the models for hospital characteristics and pandemic phases,

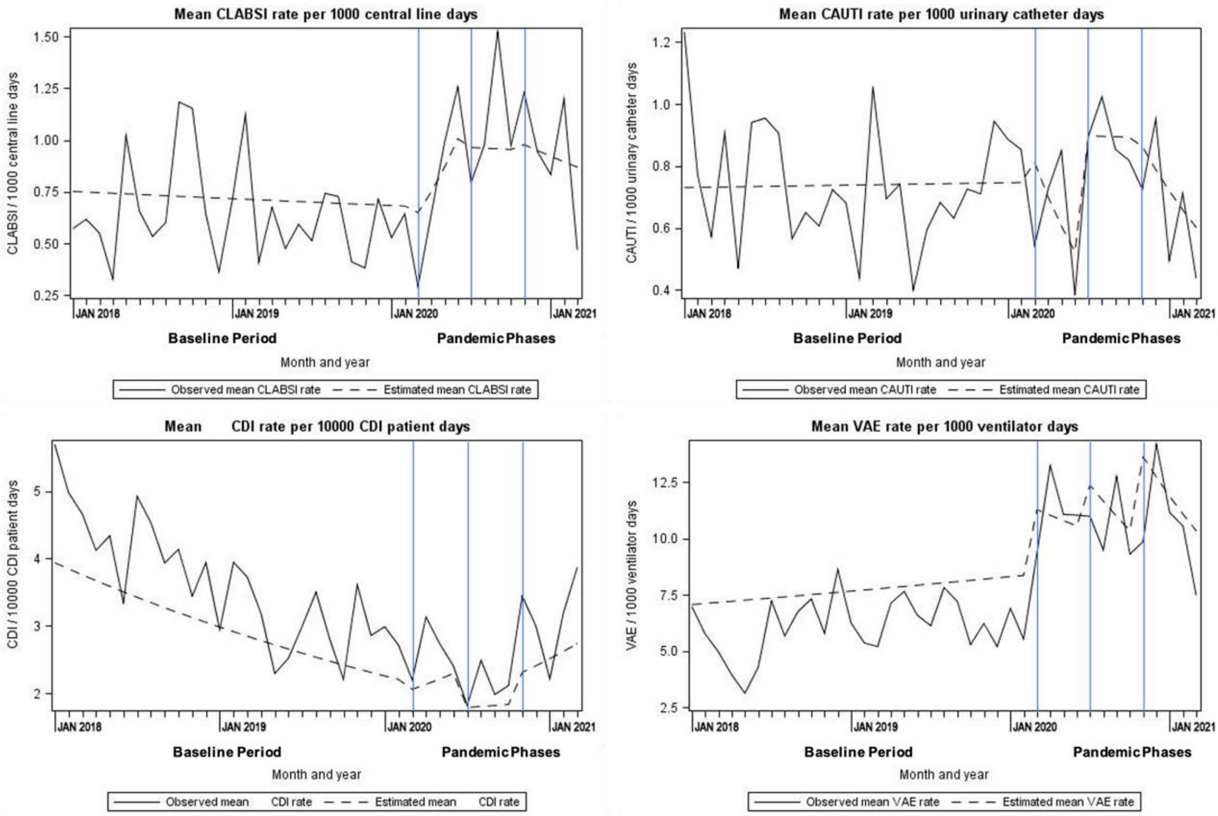

Figure 2. Segmented regression models adjusted for hospital characteristics showing CLABSI, CAUTI, CDI, and VAE trends in baseline and three pandemic phases (vertical lines). Abbreviations: CAUTI, catheter-associated urinary tract infections; CDI, *Clostridium difficile* infections; CLABSI, central-line-associated bloodstream infections; VAE, ventilator-associated events.

we cannot fully exclude the possibility of unmeasured confounding influencing the results. Finally, although our hospitals are located across multiple states, our experience may not be fully generalizable to all settings.

CONCLUSIONS

In this large multistate cohort of hospitals, the COVID-19 pandemic led to notable changes in HAI rates: VAEs increased consistently in all phases of the pandemic, whereas CLABSIs increased later in the pandemic. This impact on HAIs was disproportionately higher in smaller community hospitals. Future efforts should focus on better understanding staffing and resource challenges faced by community hospitals, and exploring opportunities to build partnerships with public health, government, local entities, and health systems. For example, expansion of tele-ID service and remote infection prevention services to rural and community hospitals will improve access and availability of expertise [37–40]. Expanding telehealth alone will not be enough, ideally, it should be accompanied by appropriate resources, infrastructure, and reimbursement models. Medicare's Physician Fee Schedule must also be rebalanced to appropriately compensate ID physicians for value-based care. Additionally, a national plan is needed to strengthen ID workforce in community hospitals to cope with increased complexity of patients [3, 15]. In order to prevent ongoing HAI escalations, healthcare facilities must invest resources in staff retention and wellbeing, and focus on "recruiting, training, and retaining" our ID workforce. Finally, hospital leaders should further evaluate capacity and infrastructure needed to address COVID-19 burden, invest in ID workforce, and collaborate with policy makers to support enhanced hospital preparedness.

Supplementary Data

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

Notes

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