Health Care-Associated Infections Among Critically Ill Children in the US, 2007–2012

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KEY WORDS

central line–associated bloodstream infections, ventilator-associated pneumonia, catheter-associated urinary tract infections, health care–associated infections, Medicaid

ABBREVIATIONS

CAUTI—catheter-associated urinary tract infection
CDC—Centers for Disease Control and Prevention
CI—confidence interval
CLABSI—central line-associated infection
HAI—health care–associated infection
IQR—interquartile range
IRR—incidence rate ratio
NHSN—National Healthcare Safety Network
PAICAP—Preventing Avoidable Infectious Complications by Avoiding Payment
PBPs—Potentially Better Practices
VAP—ventilator-associated pneumonia
VLBW—very low birth weight

Dr Patrick participated in creation of the analytic plan, was involved in the analysis, and drafted the initial manuscript; Drs Kawai, Kleinman and Mr. Jin conducted the analysis; Drs Vaz, Kassler, and Goldmann were involved in the analysis, and participated in interpretation of the results; Ms Gay coordinated recruitment and data collection; Dr Lee conceptualized the study, participated in creation of the analytic plan, was involved in the analysis, and drafted the initial manuscript; and all authors revised and approved the final manuscript.

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WHAT'S KNOWN ON THIS SUBJECT: Health care–associated infections are harmful, costly, and preventable, yet there remain limited data as to their population incidence among hospitalized neonates and children in the United States.

WHAT THIS STUDY ADDS: Incidence rates of central line–associated bloodstream infections and ventilator-associated pneumonia decreased among critically ill neonates and children during a 5-year period in the United States. National efforts to improve patient safety through decreasing HAIs have been effective.

abstract

BACKGROUND: Health care–associated infections (HAIs) are harmful and costly and can result in substantial morbidity for hospitalized children; however, little is known about national trends in HAIs in neonatal and pediatric populations. Our objective was to determine the incidence of HAIs among a large sample of hospitals in the United States caring for critically ill children from 2007 to 2012.

METHODS: In this cohort study, we included NICUs and PICUs located in hospitals reporting data to the Centers for Disease Control and Prevention's National Healthcare Safety Network for central line–associated bloodstream infections (CLABSIs), ventilator-associated pneumonias, and catheter-associated urinary tract infections. We used a time-series design to evaluate changes in HAI rates.

RESULTS: A total of 173 US hospitals provided data from NICUs, and 64 provided data from PICUs. From 2007 to 2012, rates of CLABSIs decreased in NICUs from 4.9 to 1.5 per 1000 central-line days (incidence rate ratio (IRR) per quarter = 0.96, 95% confidence interval 0.94–0.97) and in PICUs from 4.7 to 1.0 per 1000 central-line days (IRR per quarter = 0.96 [0.94–0.98]). Rates of ventilator-associated pneumonias decreased in NICUs from 1.6 to 0.6 per 1000 ventilator days (IRR per quarter = 0.97 [0.93–0.99]) and PICUs from 1.9 to 0.7 per 1000 ventilator-days (IRR per quarter = 0.95 [0.92–0.98]). Rates of catheter-associated urinary tract infections did not change significantly in PICUs.

CONCLUSIONS: Between 2007 and 2012 there were substantial reductions in HAIs among hospitalized neonates and children. *Pediatrics* 2014;134:705–712

Central line–associated bloodstream infections (CLABSIs) and ventilator-associated pneumonias (VAPs) result in significant morbidity[1,2] and mortality[3,4] among hospitalized children. Catheter-associated urinary tract infections (CAUTIs) have not been as extensively studied in pediatric populations, but are associated with poor outcomes among adults.[5,6] Health care–associated infections (HAIs) result in protracted hospital stays,[1] increased cost,[7–9] and prolonged need for mechanical ventilation.[3] They are also associated with poor neurodevelopmental outcomes, particularly for extremely low birth weight infants.[2] Despite their significant negative sequelae, HAIs are common among children in ICUs and have been reported to occur in 9% to 21% of critically ill children.[1,10–12] Further, it is estimated that a CLABSI results in additional hospital costs ranging from $16 000[12] to $39 000.[13] HAIs continue to be responsible for a substantial burden of preventable adverse events among hospitalized children and have been highlighted by national quality improvement organizations as targets for improvement.[14–17] Yet there remain limited national data on HAI incidence rates in neonatal and pediatric populations. We examined trends in CLABSI, CAUTI, and VAP incidence rates between 2007 and 2012 based on standardized surveillance data from PICUs and NICUs in the United States.

METHODS

Study Design and Population

Our study population included NICUs and PICUs located in nonfederal acute-care hospitals reporting data to the Centers for Disease Control and Prevention's (CDC) National Healthcare Safety Network (NHSN) between January 1, 2007, and September 30, 2012. The following types of hospitals were excluded: critical access hospitals, long-term care hospitals, and cancer hospitals. The hospitals in this study were a subset of hospitals participating in the Preventing Avoidable Infectious Complications by Avoiding Payment (PAICAP) study to examine the impact of national payment policies on HAI rates in the United States.[18] Hospitals were included in this study if they reported monthly data on CLABSI or VAP in NICUs, or CLABSI, VAP, or CAUTI in PICUs. We excluded pediatric stepdown units and pediatric cardiac ICUs due to low numbers of these unit types. CAUTI in the NICU was reported infrequently during this time period and thus is not reported in this study.

We used a time series design to evaluate trends in HAI rates between January 2007 and September 2012 for neonatal (NICU) and pediatric (PICU) populations. In each of these populations, we estimated rates of CLABSI per 1000 central-line days, CAUTI per 1000 urinary catheter days, and VAP per 1000 ventilator days by using standardized surveillance definitions from the CDC NHSN.[19] NHSN definitions were applied by infection control personnel before reporting data to the CDC and were based on each center's interpretation of NHSN's definitions. Because HAIs may occur more frequently among low birth weight infants,[20] we adjusted models in the NICU population for birth weight, as reported to NHSN. For descriptive purposes, we obtained information on hospital location, size, ownership, teaching status, and designation as a freestanding children's hospital from the 2009 American Hospital Association Annual Survey.[21] This study was approved by the institutional review board of Harvard Pilgrim Health Care.

Data Analysis

Descriptive statistics were generated to describe our population of hospitals. We estimated incidence rate ratios (IRRs) describing the relative change in HAI rates per quarter by using negative binomial mixed effects models with random slopes and intercepts for hospital. We aggregated rates at the quarterly rather than monthly level to increase stability of IRR estimates. Separate models were created for CLABSI, CAUTI, and VAP rates for each setting type (neonatal, pediatric) as appropriate. Birth weight ($\leq$1500 g; 1501–2500 g; $>$2500 g) was included as a covariate in neonatal models. We included interaction terms (birth weight $\times$ time) to further explore whether there were differences in HAI rates over time by birth weight category ($\leq$1500 g; 1501–2500 g; $>$2500 g). In a sensitivity analysis to determine if the 2008 CLABSI definition change (ie, requiring 2 blood cultures for common skin contaminants) affected infection rates for neonates, we reran similar mixed-effects models with a restricted study population to the 2008 to 2012 time period.[22] We also conducted a separate sensitivity analysis by using similar negative binomial models to explore whether our findings may have been influenced by the timing of initiation of NHSN reporting by restricting our analyses to hospitals consistently reporting throughout our study period (ie, reporting in at the beginning of the study period in January 2007 and also at the end of our study period in September 2012). We considered $P < .05$ to be statistically significant. Analyses were completed by using SAS version 9.3 (SAS Institute, Inc, Cary, NC).

RESULTS

Study Population

Our study included a total 174 participating US hospitals, of which 173 reported data for NICUs and 64 reported data for PICUs. ICUs varied in size, with NICUs in our sample having a median of 22 beds (interquartile range [IQR] 12–39) and PICUs a median of 12 beds (IQR 7–16). Compared with all hospitals reporting NICU and PICU data to the CDC NHSN in 2009 ($n = 363$), our sample

is similar in geographic distribution. Our hospital sample was more likely than all CDC NHSN hospitals to have >400 hospital beds (50.6% PAICAP vs 43.3% NHSN; $P < .001$) and more likely to be associated with a graduate teaching hospital (25.3% vs 18.2%; $P < .001$). There were no significant differences in hospital region, ownership, NICU level, or hospitals reporting data for PICUs. Both the PAICAP sample and CDC NHSN population included a variety of hospital types (eg, teaching and nonteaching hospitals), reflecting the diversity of settings in which neonatal and pediatric care is delivered in the United States (Table 1).

From 2007 to 2012, NICUs in our hospital sample reported a total of >5 million patient days, 1.2 million central-line days, and 380 000 ventilator days. Among participating NICUs, median central-line days per quarter was reported to be 239 (IQR 79–584) and median ventilator days 56 (IQR 1–233). PICUs reported a total of ~919 000 patient days, 403 000 central-line days, 175 000 ventilator days, and 110 000 urinary catheter days. Overall, PICUs reported median per quarter urinary catheter days of 96 (IQR 40–216), central-line days of 152 (88–499), and ventilator days of 98 (29–300).

Health Care-Associated Infection Incidence Rates

From January 2007 to September 2012, we found that incidence rates of CLABSI decreased steadily from an average of 4.9 to 1.5 per 1000 line days (IRR 0.96 per quarter, 95% confidence interval [CI] 0.94–0.97) among hospitalized neonates. This decrease in CLABSI remained statistically significant when limited to the January 2008 to September 2012 time period (Supplemental Table 3). In addition, VAP incidence rates decreased from 1.6 to 0.6 per 1000 ventilator days (IRR 0.97, 95% CI 0.93–0.99 per quarter) among neonates during the same period (Fig 1, Table 2). Infants with birth weights ≤1500 g were more likely to develop CLABSI (IRR 2.24, 95% CI 1.96–2.57) and VAP (IRR 3.48, 95% CI 2.11–5.74) when compared with infants with birth weights >2500 g (Table 2). We did not find evidence to suggest that declines in CLABSI or VAP differed over time across birth weight categories (*P* value for interaction term for CLABSI = .10; for VAP = .45).

Among hospitalized children in PICUs, incidence rates of CLABSI decreased from 4.7 to 1.0 per 1000 line days (IRR 0.96, 95% CI 0.94–0.98 per quarter) and VAP decreased from 1.9 to 0.7 per 1000 ventilator days (IRR 0.95 per quarter, 95% CI 0.92–0.98), whereas CAUTI incidence rates did not change significantly (Fig 2, Table 2). These findings were similar for hospitals that consistently reported throughout the entire study period, as shown in Supplemental Table 4.

TABLE 1 Characteristics of PAICAP Hospitals (n = 174) Versus All Hospitals Reporting NHSN Data on NICU or PICU Infection Rates in 2009

	PAICAP Hospitals, n = 174	2009 NHSN Hospitals, n = 363	*P* Value
	n (%)	*n* (%)	
Hospital region			.62
Midwest	35 (20.2)	64 (17.6)	
Northeast	65 (37.6)	144 (39.7)	
South	35 (20.2)	76 (20.9)	
West	39 (22.4)	79 (21.8)	
Hospital size (number of beds)			<.001
<100	2 (1.1)	37 (10.2)	
100–399	84 (48.3)	169 (46.6)	
≥400	88 (50.6)	157 (43.3)	
Type of hospital ownership			.09
For-profit	20 (11.5)	35 (9.6)	
Not-for-profit	134 (77.0)	296 (81.5)	
Public	20 (11.5)	32 (8.8)	
Teaching hospital type			<.001
Graduate teaching	44 (25.3)	66 (18.2)	
Major teaching	71 (40.8)	150 (41.3)	
Minor teaching	9 (5.2)	39 (10.7)	
Nonteaching	50 (28.7)	108 (29.8)	
NICU type within hospital[a]			
Level II NICU[b]	11 (6.3)	16 (4.4)	.13
Level III NICU[c]	85 (48.9)	168 (46.3)	.88
Level II/III NICU[d]	90 (51.7)	161 (44.4)	.13
PICU within hospital[e]	64 (36.8)	150 (41.3)	.07

[a] A total of 174 PAICAP hospitals reported NICU data, with 64 of these hospitals also reporting PICU data. Hospitals could have >1 NICU type; thus, the sum total of the hospitals across NICU types does not equal the total number of hospitals with NICUs.
[b] Level II NICU: In NHSN, a Level II nursery is considered a Step Down Neonatal Nursery ward and provides care for infants born at >32 weeks' gestation and weighing ≥1500 g.
[c] Level III NICU–Level III (subspecialty) NICUs are subdivided into 3 categories. Level IIIA has the capabilities to provide comprehensive care for infants born at >28 weeks' gestation and weighing >1000 g. Level IIIB has the capabilities to provide comprehensive care for extremely low birth weight infants (≤1000 g and ≤28 weeks' gestation). Level IIIC has the capabilities of a level IIIB NICU and also is located within an institution that has the capability to provide extracorporeal membrane oxygenation and surgical repair of complex congenital cardiac malformations that require cardiopulmonary bypass.
[d] Level II/III NICU: Combined nursery housing both Level II and Level III newborns and infants.
[e] Of the 64 PAICAP hospitals with PICUs, all but 1 hospital also had NICUs.

DISCUSSION

Among a large sample of hospitals in the United States caring for critically ill neonates and children, we found substantial declines in several HAI incidence rates between January 2007 and September 2012. In addition to improving important patient outcomes, we estimate the reduction in CLABSI among hospitals in our sample resulted in savings of $131 million (~$61 million in NICUs; ~$70 million for PICUs)[12,13] to these hospitals during our study period. For critically ill neonates, incidence rates of CLABSI decreased by 4% per quarter (61% decline during

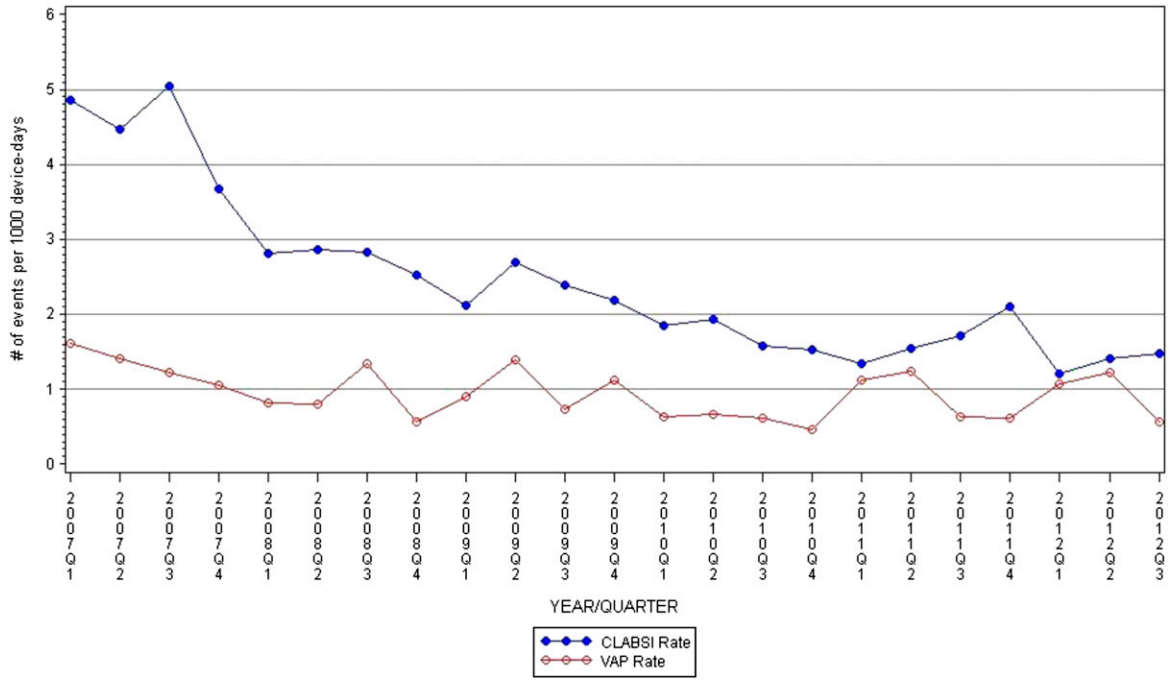

FIGURE 1
Rates of CLABSI and VAP in NICUs, January 2007 to September 2012. CLABSI: 2615 events; 5 026 125 patient days; 1 222 393 line days. VAP: 347 events; 4 197 644 patient days; 380 949 ventilator days.

the study period), whereas incidence rates of VAP declined by 3% per quarter (50% decline during the study period), representing sustained improvement for this vulnerable population. These findings are similar to reported decreases in CLABSI for neonates in state[23–26] and multistate collaborations.[27]

Similar to previous studies,[1,20] we found that very low birth weight (VLBW) infants were more likely to have CLABSI or VAP than normal birth weight infants. When compared with normal birth weight infants, VLBW infants were >2 times more likely to have CLABSI and nearly 3.5 times more likely to develop VAP. This may be due to decreased innate and adaptive immunity of VLBW infants[28] and higher rates of device utilization, the combination of which increases the risk of HAIs substantially. Despite these challenges, VLBW infants have been the subject of large-scale quality improvement efforts to reduce CLABSI over the past decade, and this likely contributes to the substantial reductions seen. For example, the Vermont Oxford Network, a collaboration that now includes more than 900 hospitals, uses "Potentially Better Practices" (PBPs) as a bundle of possible interventions for NICUs to adapt to the unique needs and culture of their unit. Such PBPs are part of a broad-quality effort that includes data feedback, quality improvement training, and site visits. Examples of elements of PBPs used by participating centers include promoting hand washing, reducing hyperalimentation (as a means to reduce device utilization), implementing protocols for skin care of extremely low birth weight infants to reduce skin breakdown, reducing laboratory testing and venipunctures, and establishing protocols for line-care maintenance and access. The organizers note that PBPs are used differently in different units; therefore, they hypothesize that reductions in HAI seen as part of their collaborative are as much a part of local multidisciplinary

TABLE 2 Regression Models to Evaluate Changes in Quarterly Rates Over Time for CLABSI, CAUTI, and VAP, January 2007 to September 2012

	CLABSI		VAP		CAUTI	
	IRR (95% CI)	*P* Value	IRR (95% CI)	*P* Value	IRR (95% CI)	*P* Value
NICU[a]						
Time[b]	0.96 (0.94–0.97)	<.001	0.97 (0.93–0.99)	.045	N/A	N/A
Birth weight,[c] g						
≤1500	2.24 (1.96–2.57)		3.48 (2.11–5.74)			
1500–2500	1.12 (0.94–1.34)	<.001	2.10 (1.12–3.92)	<.001		
>2500	1.0 (Ref)		1.0 (Ref)			
PICU						
Time[b]	0.96 (0.94–0.98)	<.001	0.95 (0.92–0.98)	<.001	1.01 (0.99–1.04)	.30

N/A, not applicable.
[a] Interaction terms for time × birth weight were not significant for the CLABSI ($P = .10$) or VAP ($P = .45$) models.
[b] IRR is interpreted as percentage change per quarter (eg, IRR of 0.96 is a decrease of 4% per quarter).
[c] IRR for birth weight categories are interpreted similar to odds ratios (e.g. IRR of 1.12 of 1500–2500 group reflects that this group has a 12% increased odds of CLABSI when compared to the reference group of >2500 g).

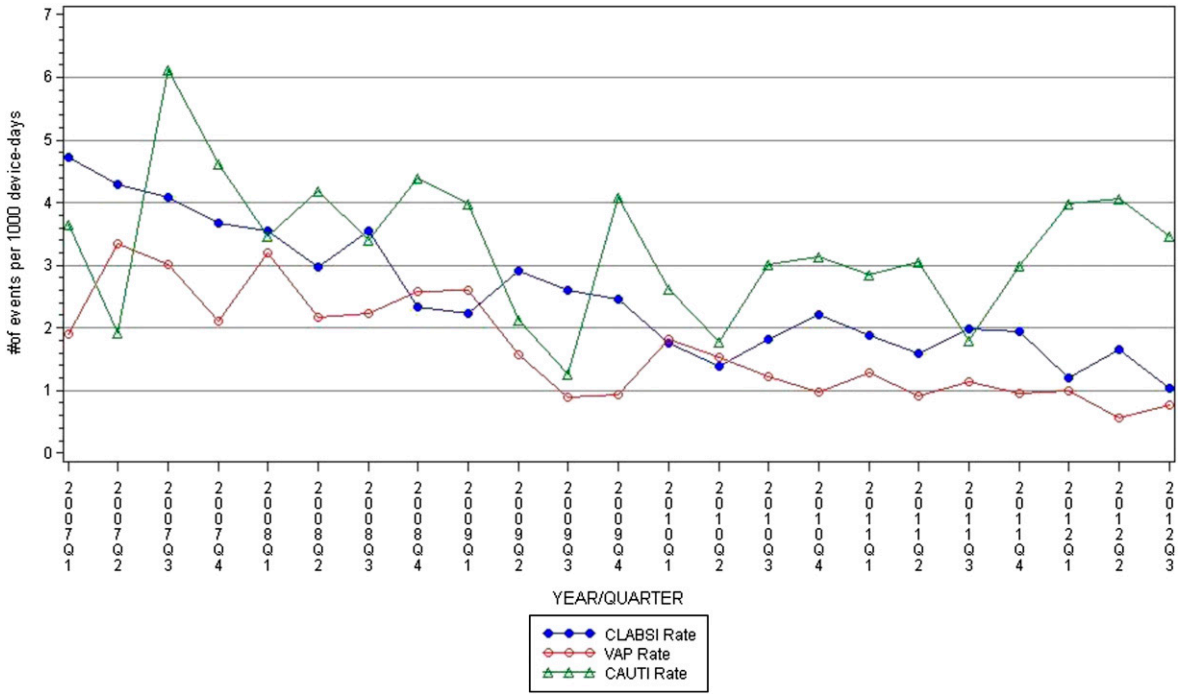

FIGURE 2

Rates of CLABSI, VAP, and CAUTI in PICUs, January 2007 to September 2012. CLABSI: 888 events; 919 200 patient days; 403 307 line days. VAP: 261 events; 825 868 patient days; 174 509 ventilator days. CAUTI: 352 events; 879 409 patient days; 109 835 catheter days.

efforts focused on unit change to improve clinical outcomes as it is on the individual elements of PBPs.[29]

Among critically ill children in PICU settings between January 2007 and September 2012, we found that incidence rates of CLABSI decreased by 4% per quarter (61% decline during the study period), and incidence of VAP decreased by 5% per quarter (76% during the study period). These findings are similar to a recent study describing decreasing trends among HAIs in adults[18] and in a multistate PICU collaboration,[30] and may be the result of a national focus on reducing CLABSI by government agencies[31] and quality improvement organizations.[14] In our study, we found that CAUTI incidence rates remained unchanged throughout the study period; however, several changes to the CAUTI surveillance definition over the past year may have precluded our ability to assess whether meaningful improvements have occurred. Furthermore, CAUTI has not received the same level of national attention among pediatric quality improvement networks as CLABSI or VAP. However, it is important to note that when improvement efforts have focused on eliminating CAUTI in critically ill children, they have yielded decreases in this important HAI.[32]

Monitoring recent trends in HAIs among children is particularly relevant as national policies to prevent HAIs relevant to these populations are enacted. In 2010, the Patient Protection and Affordable Care Act mandated that Medicaid, the payer for more than one-third of US children,[33] begin penalizing hospitals for certain HAIs beginning on July 1, 2012.[34] The policy, similar to the one enacted by Medicare in 2008,[35] aims to motivate hospitals through financial incentives. In the past, hospitals may have received additional payment for care associated with HAIs. The policies enacted by Medicaid and Medicare aim to eliminate these perverse financial incentives, in an attempt to reduce rates of HAIs and other preventable complications. As policymakers continue their efforts to align quality and payment through the Medicaid program, we will need to carefully consider the potential financial impact on hospitals that care for high-risk neonates and children and be mindful that rates of HAI for children were decreasing before policy implementation.

Our study has several potential limitations. First, although data among our cohort were gathered from a large group of US hospitals in 39 states that serve neonatal and pediatric patients, it did not include all US hospitals, possibly limiting its generalizability. Hospitals included in our study either may have had higher initial rates of HAIs or may have had more focused efforts on HAI reduction than other US hospitals. Additionally, quality improvement approaches may have differed between the hospitals included in this study versus those in the general population of US hospitals. There also may be regional differences in mandated hospital HAI reporting that may affect our data. Second, despite the use of rigorous clinical data and standardized HAI

definitions, inter- and intrahospital variability in implementation of NHSN surveillance definitions may still occur.[36] Nonetheless, NHSN surveillance data are currently the best available data source for evaluating rates of device-associated infections in the United States, in comparison with alternative data sources, such as hospital billing data.[37,38] Third, the number of hospitals reporting during our study period increased over time, which may affect the interpretation of our findings if the composition of these institutions differed in characteristics that affect rates of HAIs. However, when we restricted the analysis to hospitals that consistently reported during the study period, our findings were similar. Although the overall burden of HAIs has dramatically declined, we were likely underpowered to detect differences in rates of decline by birth weight category (ie, effect modification). Next, some have expressed concern regarding the reliability of the NHSN VAP definition, especially among neonates, which could affect our results.[39,40] Finally, pediatric stepdown units and pediatric cardiac ICUs were excluded from our study because of small numbers, limiting our ability to generalize findings to these settings.

CONCLUSIONS

Over the past several years, US hospitals made substantial improvements in preventing harm to hospitalized neonates and children by reducing HAIs. HAI incidence rates fell dramatically among neonates of all birth weights and among children, reducing their risk of morbidity and mortality. Eliminating HAIs must remain a prominent quality improvement goal to protect our most vulnerable patients.

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