PEDIATRICS®

OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Reducing PICU Central Line–Associated Bloodstream Infections: 3-Year Results

Marlene R. Miller, Matthew F. Niedner, W. Charles Huskins, Elizabeth Colantuoni, Gayane Yenokyan, Michele Moss, Tom B. Rice, Debra Ridling, Deborah Campbell, Richard J. Brilli and the National Association of Children's Hospitals and Related Institutions Pediatric Intensive Care Unit Central Line –Associated Bloodstream Infection Quality Transformation Teams

Pediatrics 2011;128;e1077; originally published online October 24, 2011;
DOI: 10.1542/peds.2010-3675

Reducing PICU Central Line–Associated Bloodstream Infections: 3-Year Results

AUTHORS: Marlene R. Miller, MD, MSc,[a,b,c] Matthew F. Niedner, MD,[d] W. Charles Huskins, MD, MSc,[e] Elizabeth Colantuoni, PhD,[f,g] Gayane Yenokyan, MD, PhD,[g] Michele Moss, MD,[h] Tom B. Rice, MD,[i] Debra Ridling, RN, MS, CCRN,[j] Deborah Campbell, RNC, MSN, CCRN,[k] Richard J. Brilli, MD,[l] and the National Association of Children's Hospitals and Related Institutions Pediatric Intensive Care Unit Central Line–Associated Bloodstream Infection Quality Transformation Teams

Departments of [a]Pediatrics and [f]Anesthesia and Critical Care Medicine, School of Medicine, and Departments of [b]Health Policy and Management and [g]Biostatistics, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, Maryland; [c]National Association of Children's Hospitals and Related Institutions, Alexandria, Virginia; [d]Department of Pediatrics and Communicable Diseases, School of Medicine, University of Michigan, Ann Arbor, Michigan; [e]Division of Pediatric Infectious Diseases, Mayo Clinic, Rochester, Minnesota; [h]Department of Cardiology, Arkansas Children's Hospital, Little Rock, Arkansas; [i]Department of Pediatrics, Children's Hospital of Wisconsin, Milwaukee, Wisconsin; [j]Department of Pediatrics, Children's Hospital and Regional Medical Center, Seattle, Washington; [k]Department of Pediatrics, Kosair Children's Hospital, Louisville, Kentucky; and [l]Department of Pediatrics, Nationwide Children's Hospital, Columbus, Ohio

KEY WORDS

bloodstream infections, children, nosocomial infections, pediatric intensive care unit

ABBREVIATIONS

CLA-BSI—central line-associated bloodstream infection
CDC—Centers for Disease Control and Prevention
NHSN—National Healthcare Safety Network
NACHRI—National Association of Children's Hospitals and Related Institutions
CI—confidence interval

www.pediatrics.org/cgi/doi/10.1542/peds.2010-3675

doi:10.1542/peds.2010-3675

Accepted for publication Jul 28, 2011

Address correspondence to Marlene R. Miller, MD, MSc, Department of Pediatrics, Johns Hopkins University Medical School, 200 N Wolfe St, Room 2094, Baltimore, MD 21287. E-mail: mmille21@jhmi.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: *The authors have indicated they have no financial relationships relevant to this article to disclose.*

WHAT'S KNOWN ON THIS SUBJECT: Pediatric central line–associated bloodstream infections (CLA-BSIs) are common, are costly (up to $45 000 per event), cause considerable morbidity, and are the focus of significant research and quality improvement efforts.

WHAT THIS STUDY ADDS: This is the first study to show sustained and continually decreasing PICU CLA-BSI rates over an extended period of 3 years and across multiple PICUs.

abstract

OBJECTIVES: To evaluate the long-term impact of pediatric central line care practices in reducing PICU central line–associated bloodstream infection (CLA-BSI) rates and to evaluate the added impact of chlorhexidine scrub and chlorhexidine-impregnated sponges.

METHODS: A 3-year, multi-institutional, interrupted time-series design (October 2006 to September 2009), with historical control data, was used. A nested, 18-month, nonrandomized, factorial design was used to evaluate 2 additional interventions. Twenty-nine PICUs were included. Two central line care bundles (insertion and maintenance bundles) and 2 additional interventions (chlorhexidine scrub and chlorhexidine-impregnated sponges) were used. CLA-BSI rates (January 2004 to September 2009), insertion and maintenance bundle compliance rates (October 2006 to September 2009), and chlorhexidine scrub and chlorhexidine-impregnated sponge compliance rates (January 2008 to June 2009) were assessed.

RESULTS: The average aggregate baseline PICU CLA-BSI rate decreased 56% over 36 months from 5.2 CLA-BSIs per 1000 line-days (95% confidence interval [CI]: 4.4–6.2 CLA-BSIs per 1000 line-days) to 2.3 CLA-BSIs per 1000 line-days (95% CI: 1.9–2.9 CLA-BSIs per 1000 line-days) (rate ratio: 0.44 [95% CI: 0.37–0.53]; $P < .0001$). No statistically significant differences in CLA-BSI rate decreases between PICUs using or not using either of the 2 additional interventions were found.

CONCLUSIONS: Focused attention on consistent adherence to the use of pediatrics-specific central line insertion and maintenance bundles produced sustained, continually decreasing PICU CLA-BSI rates. Additional use of either chlorhexidine for central line entry scrub or chlorhexidine-impregnated sponges did not produce any statistically significant additional reduction in PICU CLA-BSI rates. *Pediatrics* 2011; 128:e1077–e1083

Central line–associated bloodstream infections (CLA-BSIs) are common among children, are costly, cause considerable morbidity, and are the focus of significant research and quality improvement efforts.[1–14] In 2006–2008, the pooled mean rate of CLA-BSIs among all ICU types in the Centers for Disease Control and Prevention (CDC) National Healthcare Safety Network (NHSN) system ranged from 1.3 to 5.5 CLA-BSIs per 1000 catheter days.[15–18] With pooled mean rates of 3.3 CLA-BSIs per 1000 catheter days for pediatric cardiothoracic ICUs and 3.0 CLA-BSIs per 1000 catheter days for pediatric medical/surgical ICUs, PICUs have the third and fourth highest rates among 16 unit types.[16] The higher rates in pediatric settings likely derive from differences in how central lines are handled for adult and pediatric patients, and they make pediatric units an ideal environment for learning and process improvement.

Since October 2006, the National Association of Children's Hospitals and Related Institutions (NACHRI) has supported an ongoing quality transformation effort, involving multiple PICUs, to identify and to test the impact of pediatrics-specific catheter care practices in reducing CLA-BSIs. In 2010, we reported on a new, effective, central line maintenance bundle that was able to reduce the rate of pediatric CLA-BSIs by nearly one-half in 29 PICUs during the first 12 months after implementation.[19] We now report on longer-term, 3-year outcomes of these efforts through September 2009. In addition, we report on a nonrandomized, nested, factorial design study conducted for 18 consecutive months during these 3 years to evaluate the effects of either chlorhexidine scrub on central line caps/access points before all line entries or chlorhexidine-impregnated sponge (Biopatch [Ethicon, Somerville, New Jersey]) application on CLA-BSI rates.

METHODS

We described previously the study design, setting, participants, objectives, interventions, and measures.[19] Briefly, since October 2006, the NACHRI has supported collaborative work among >65 PICUs, focused on reducing CLA-BSI rates. The initial cohort included 29 PICUs and is the focus of this 3-year postintervention report encompassing October 2006 to September 2009. The study design is a multi-institutional, interrupted time-series with historical control data from January 2004 to September 2006. The goal of this ongoing effort is to eliminate CLA-BSIs by reliably implementing pediatrics-specific insertion and catheter care maintenance bundles (Table 1).

Data on 2 process measures, that is, insertion bundle compliance and maintenance bundle compliance, were collected. The audit process was described previously.[19] Our outcome measure was the monthly PICU CLA-BSI rate, defined as the number of CLA-BSI cases per 1000 line-days, and data were collected by trained, hospital-based, infection control practitioners, in accordance with CDC definitions.[20] In 2008, the NHSN definition for CLA-BSI was revised, most notably to require 2 positive blood culture results with organisms considered to be common skin contaminants.[21] Our efforts incorporated this definitional change both in practice and in analyses.

In addition to core efforts in reliably implementing and sustaining insertion and maintenance bundle care practices to reduce CLA-BSI rates, we conducted a nested, 18-month (January 2008 to June 2009), nonrandomized, factorial design study to examine the impact of 2 other interventions. The teams were voluntarily divided into 4 groups, that is, a control group (8 PICUs), a group using chlorhexidine scrub on central line caps/access points with each central line entry (11 PICUs), a group using chlorhexidine-impregnated sponges with all central

TABLE 1 Central Line Care Bundles

Insertion bundle
Hand washing before procedure
Chlorhexidine scrub at insertion site (30-s scrub [2 min for groin] and 30–60-s air dry for all children ≥2 mo of age)
No iodine skin preparation; no iodine ointment at insertion site
Prepackaged or filled insertion cart, tray, or box
Insertion checklist (with staff empowerment to stop nonemergency procedure if sterile insertion practice not being followed)
Full sterile barrier for providers and patient
Insertion training for all providers (eg, slides and video)
Maintenance bundle
Daily assessment of whether catheter is needed
Catheter site care
No iodine ointment
Chlorhexidine scrub to site with dressing changes (30-s scrub and 30-s air dry)
Change gauze dressings every 2 d unless soiled, dampened, or loosened (CDC recommended)
Change clear dressing every 7 d unless soiled, dampened, or loosened (CDC recommended)
Prepackaged dressing change kit (each unit to define package contents)
Catheter hub/cap/tubing care
Replace administration sets, including add-on devices, no more frequently than every 72 h unless soiled or suspected to be infected
Replace tubing used to administer blood, blood products, or lipids within 24 h after initiation of infusion (CDC recommended)
Change caps no more often than 72 h (or according to manufacturers' recommendations), but caps should be replaced when administration set is changed (CDC recommended)
Prepackaged cap change kit/cart/central location (elements designated by local institution)

line site care (5 PICUs), and a group using both chlorhexidine scrub and chlorhexidine-impregnated sponges (5 PICUs). Furthermore, given the strong motivation by many PICUs to reduce CLA-BSIs before our nested 18-month study, some of the PICU teams had implemented 1 or both of these additional interventions but had not done so universally for all patients with a variable degree of standardization and with no adherence monitoring. Once the nested factorial study was added to the collaborative work, all teams audited compliance with use of the core insertion and maintenance bundles and the 2 supplemental interventions according to standardized protocols. The chlorhexidine scrub intervention was used for all central line access via cap-type access points (except for emergency access) and consisted of a 30-second scrub followed by a 30-second air drying. Compliance with this intervention was audited by collecting data for all PICU patients for 48 hours per month (typically divided into 8- to 12-hour continuous periods of data collection) and recording whether chlorhexidine was used for each line entry. For chlorhexidine-impregnated sponges, the protocol involved applying a chlorhexidine-impregnated sponge at the central line entry site at the time of line insertion and applying a new sponge with each dressing change, according to the manufacturer's recommendations. Compliance was assessed through weekly examinations of all patients in the PICU. Monthly data were analyzed from January 2004 through September 2009 and subdivided into 3 time periods, namely, a preintervention baseline period (January 2004 to September 2006; months 1–33), a ramp-up period of intervention deployment (the initial 3 months, from October 2006 to December 2006; months 34–36), and a postintervention period (January 2007 to September 2009; months 37–69).

We used marginal generalized linear models assuming a negative binomial distribution with logarithmic link to estimate the average CLA-BSI rate as a function of time within each period (different temporal slopes within the baseline, ramp-up, and stable periods), and adjustments were made for PICU-level characteristics (geographic region, average length of stay, and bed capacity). To quantify the effect of the revised NHSN definition of CLA-BSIs, we included a main effect of time for months January 2008 through September 2009; this main effect allowed the average CLA-BSI rate to change because of the revised NHSN definition starting in January 2008. To account for the clustering effect of CLA-BSIs within individual PICUs, the models were fit by using generalized estimating equations assuming an autoregressive working correlation structure.[22] Robust variance estimates were obtained to account for any misspecification of the working correlation structure.

To explore the effects of the factorial design nested study (control group, chlorhexidine scrub group, chlorhexidine-impregnated sponge group, and dual intervention group), we modeled the average CLA-BSI rates over time separately for both of the additional interventions. The PICU factorial design group membership was permitted to change before January 2008, reflecting the historical nonprotocolized use of these 2 additional interventions by some PICUs. Between January 2008 and June 2009, the additional intervention group membership was not changed and audited compliance data were collected regularly. Average CLA-BSI rates were modeled over time separately for each group by using a marginal generalized linear model incorporating 3 time periods and addressing 2 phases of use of these 2 additional interventions (nonprotocolized use in the ramp-up period from October 2006 to December 2006 and in postintervention year 2007 and protocolized formal factorial design in January 2008 to June 2009). The models included indicators for factorial design group (with the control group as reference) and the interaction of time and each additional intervention. An autoregressive working correlation structure was specified, and SEs were estimated with robust variance estimation. All analyses were conducted by using SAS 9.2 (SAS Institute, Cary, NC).

RESULTS

Characteristics of the 29 PICUs in the NACHRI PICU CLA-BSI collaborative are presented in Table 2. Most PICUs were mixed PICUs and cardiac ICUs; 2 of them were solely cardiac ICUs. The majority of facilities were level 1 trauma centers and performed solid-organ transplants, bone marrow trans-

TABLE 2 Characteristics of 29 Participating ICUs

Characteristic	*n* (%)
Type of unit	
PICU	9 (31)
PICU/cardiac ICU	18 (62)
Cardiac ICU	2 (7)
No. of beds	
10–16	12 (41)
17–27	13 (45)
28–36	4 (14)
Annual mean PICU length of stay	
2.7–4.5 d	14 (48)
4.6–6.3 d	12 (41)
6.4–9.6 d	3 (10)
Yearly total of PICU patient-days	
2100–3700	10 (34)
3701–6300	10 (34)
6301–8700	9 (31)
No. of ICU admissions in 2005	
300–900	10 (34)
901–1800	15 (52)
1801–2400	4 (14)
Institution is level 1 trauma center	19 (66)
Institution performs solid-organ transplants	25 (86)
Institution performs bone marrow transplants	21 (72)
ICU performs extracorporeal membrane oxygenation	26 (90)

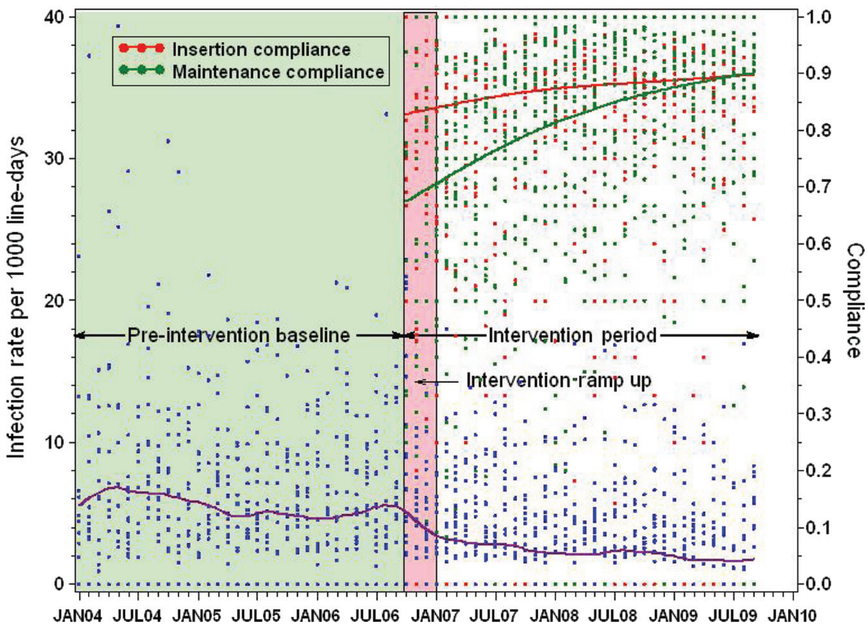

FIGURE 1
Plot of CLA-BSI rates and insertion and maintenance compliance rates (and 95% CIs) in the preintervention baseline and intervention periods for the 29 PICUs.

plants, and extracorporeal membrane oxygenation.

A total of 1759 CLA-BSI events were reported by the 29 PICUs during the 36-month postintervention study period (501 911 total line-days). Figure 1 presents the average monthly PICU CLA-BSI rates during the study period. The average aggregate baseline PICU CLA-BSI rate for the 29 ICUs was 5.2 CLA-BSIs per 1000 line-days (95% confidence interval [CI]: 4.4–6.2 CLA-BSIs per 1000 line-days) for the period from January 2004 to September 2006. After initiation of the interventions, the rate began to decrease in the ramp-up period (4.3 CLA-BSIs per 1000 line-days [95% CI: 3.2–5.7 CLA-BSIs per 1000 line-days]) and decreased to an average postintervention rate of 2.3 CLA-BSIs per 1000 line-days (95% CI: 1.9–2.9 CLA-BSIs per 1000 line-days) for the period from January 2007 to September 2009. This indicates a significant difference between the baseline period CLA-BSI rate and the postintervention period CLA-BSI rate (rate ratio: 0.44 [95% CI: 0.37–0.53]; $P <$ .0001); there was a decrease in the CLA-BSI rate of 56%.

The marginal generalized linear model was used to estimate the monthly changes in CLA-BSI rates during the baseline, ramp-up, and postintervention periods. The CLA-BSI rate decreased by an estimated 1% per month in the baseline period; however, this decrease was not statistically significant ($P =$ .307). During the ramp-up period, the estimated decrease was ~11% per month (95% CI: 3%–18% decrease per month; $P =$ .006). During the postintervention period, the infection rate decreased by 2% per month (95% CI: 1% increase to 4% decrease per month; $P =$ .088); however, this decrease reached only marginal statistical significance. The infection rate decreased by ~15% in January 2008 because of the change in the NHSN definition for CLA-BSIs; however this decrease was not statistically significant ($P =$ .448). The estimates were similar after adjustment for geographical region, average length of stay, and bed capacity (Table 3).

The results of the factorial design evaluation of the 2 additional interventions (chlorhexidine scrub of central line caps/access points and chlorhexidine-impregnated sponges) indicated that the CLA-BSI rates decreased for all 4 groups (Fig 2). There were no statistically significant differences in the rates of decrease among the 4 groups, during the nonprotocolized use of these additional interventions from

TABLE 3 Results of Generalized Linear Marginal Models Examining Temporal Trends and Effects of PICU-Related Characteristics on CLA-BSI Rates

Variables	Unadjusted Models		Adjusted Models	
	Rate Ratio (95% CI)	*P*	Rate Ratio (95% CI)	*P*
Time periods (per month)				
Baseline decrease (January 2004 to September 2006)	0.99 (0.98–1.01)	.307	0.99 (0.98–1.01)	.339
Ramp-up period decrease (October 2006 to December 2006)	0.89 (0.82–0.97)	.006	0.89 (0.81–0.97)	.006
Stable decrease (January 2007 to September 2009)	0.98 (0.96–1.01)	.088	0.98 (0.96–1.01)	.084
NHSN definition change (January 2008 to September 2009)	0.86 (0.57–1.28)	.448	0.85 (0.58–1.26)	.416
Length of stay (per day)	0.99 (0.90–1.10)	.867	1.00 (0.88–1.13)	.962
No. of beds (per 100)	2.04 (0.18–23.51)	.569	2.44 (0.23–25.60)	.456
Region				
Northeast vs West	0.83 (0.48–1.42)	.494	0.84 (0.5–1.4)	.497
Midwest vs West	0.85 (0.54–1.36)	.507	0.82 (0.53–1.27)	.385
South vs West	0.95 (0.59–1.53)	.824	0.94 (0.59–1.5)	.802

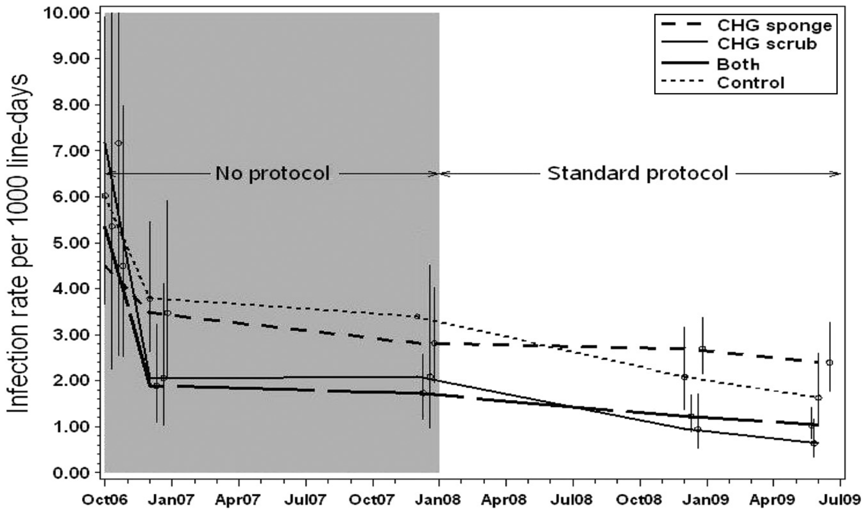

FIGURE 2

Factorial design evaluation of chlorhexidine scrub of central line caps/access points and chlorhexidine-impregnated sponges using 4 groupings of PICUs, showing CLA-BSI rates (and 95% CIs) during nonprotocolized and protocolized periods of evaluation. CHG indicates chlorhexidine gluconate.

October 2006 to December 2007 or during the protocolized use from January 2007 to June 2009.

DISCUSSION

Results from the 3-year NACHRI quality transformation effort focused on reducing CLA-BSI rates in 29 PICUs show that such targeted efforts can achieve significant decreases in CLA-BSI rates, that the rates continue to decrease over time with ongoing focused efforts, and that the overall decrease can be sustained for an extended period. These results attest to the sustainability of efforts to improve central line maintenance care, the main driver for CLA-BSI rate reduction in pediatrics.[19] Maintenance care practices are complex and multidimensional for nurses to master reliably. Furthermore, they need to be performed consistently and with precision many times each day for each patient. This focused, 3-year, collaborative effort with repetitive teaching on how to achieve reliable consistent use of the bundles resulted in statistically significant decreases in CLA-BSI rates, building on the reduction achieved during the first year. Sustaining care practice changes that achieve measureable reductions in preventable harm (hospital-acquired CLA-BSIs) often is more difficult that the initial work needed to achieve improvement, and this report demonstrates that an extended period of improvement can be achieved. Using literature-based adult estimates of CLA-BSI–attributable mortality rates and pediatrics-specific data on CLA-BSI morbidity, such as a cost of $45 000 per CLA-BSI episode, we estimate (recognizing the potential imprecision of these estimates and the limitations of using them to quantify the impact of this work) that the 29 PICUs participating in this 3-year collaborative have prevented >900 CLA-BSIs, saved >100 children's lives by avoiding CLA-BSIs, and saved more than $31 million in CLA-BSI–attributable health care costs, on the basis of 2.5 years of historic baseline performance data for each team.[4,5,12,14,22] In terms of the costs of this effort to the 29 institutions, the estimates we can provide are crude, because of significant variations in institutional contextual issues such as the size of the PICU, the number of PICUs, the baseline rate of CLA-BSIs, baseline adherence to bundle practices, local influences of public reporting and regulatory requirements, institutional quality resources, institutional financial status, local safety culture, local availability of institutional quality thought leaders and quality improvement consultants, institutional training resources, and institutional quality incentives.[23] Teams participating in our effort, over the course of the 3-year period, paid an estimated annual "pay to participate" fee of $9000 (fees were adjusted annually to reflect operating costs, including staff members, faculty members, data systems, and meeting facilities), paid approximately $5000 per year to permit 2 or 3 team members to travel to 2 face-to-face learning session meetings each year (although some teams voluntarily sent many more staff members to learning session meetings), and needed ~0.4 full-time equivalents (as a crude average), typically registered nurse–level, to support data collection, data entry, and local quality improvement efforts. Collectively, the "return on investment" from this effort was substantial; 29 institutions paid approximately $75 000 in each of 3 years in expenses to support this work, which resulted in $31 million in savings to the health care system.

To our knowledge, this is the first study to show sustained and continually decreasing PICU CLA-BSI rates over an extended period of 3 years and across multiple PICUs, correlated directly with implementation of a standardized approach to central line care. For children in ICUs, however, the main driver for CLA-BSI rate reductions is the daily central line maintenance care delivered primarily by nurses.[19] Given the manyfold greater numbers of nursing staff members employed in PICUs, compared with physician staff members, and given the fact that any 1 central line has 1 episode of insertion but hundreds of episodes of maintenance care, the fact that PICU CLA-BSI rates decrease more gradually than seen with adult ICU efforts is not surprising.[13] Similar gradual decreases in pediatric CLA-BSI rates were reported for a single cardiac PICU and a large cohort of NICUs.[24,25] Focused attention only on central line insertion, as is occurring in the adult ICU community, is not likely to achieve significant success in the PICU community.

Although these PICUs were focused on consistently adhering to the standard best practice bundles for central line insertion and maintenance care, addition of either a chlorhexidine scrub at central line access points or chlorhexidine-impregnated sponges at insertion sites did not provide significantly greater reductions in CLA-BSI rates, compared with those achieved through reliable adherence to use of the core bundles. These negative results are most appropriately considered in the context that PICU teams were focused on consistently using best practices for both insertion and central line maintenance care in addition to evaluating these 2 additional strategies. The literature contains inconclusive evidence that either of these 2 interventions is linked to CLA-BSI rate reductions among children.[26–29]

There are several limitations to this study. First, the CLA-BSI definition used by the CDC does not take into account the number of central lines and/or lumens per patient-day. Furthermore, the CDC definition does not necessarily identify truly preventable CLA-BSIs. Because the CDC CLA-BSI definition is widely accepted and is commonly used by most hospitals, however, it offered the best method to limit variations in definition interpretation. Variability in the application of this definition, as documented in other settings, might have influenced our findings.[30,31] Second, the factorial design evaluation of both chlorhexidine scrub for central line entry and chlorhexidine-impregnated sponges was not randomized and was influenced by teams using these tools in a nonprotocolized manner before the beginning of the 18-month evaluation. Despite these factors, it is compelling that, in the context of reliable use of the core bundle practices, neither of these supplemental interventions provided any additional benefit in CLA-BSI rate reductions. Overall, our 3-year effort shows that focus on reliable adherence to core practices for insertion and maintenance care may be the best way to further CLA-BSI rate reductions, rather than adding new bundle components (eg, chlorhexidine scrub for entry of all central line caps/access points and chlorhexidine-impregnated sponges).

CONCLUSIONS

CLA-BSIs are a preventable cause of patient harm for critically ill children. Our 3-year quality transformation effort, conducted in 29 PICUs, shows that focused consistent adherence to both insertion and maintenance bundles produces sustained and continually decreasing CLA-BSI rates. The key issues for pediatrics are as follows: (1) understanding that the main driver for further reducing pediatric CLA-BSI rates is daily maintenance care for central lines and (2) accepting that reliably performing tasks that occur multiple times per day for each PICU patient is a challenging but crucial body of work for all pediatric providers. In the context of our bundles of care, supplemental use of either chlorhexidine for central line entry scrub or chlorhexidine-impregnated sponges did not produce any appreciable additional reduction in CLA-BSI rates. More study is needed to determine the optimal maintenance care bundle that will facilitate elimination of pediatric CLA-BSIs and be sustainable.

REFERENCES

1. Mermel L. Prevention of intravascular catheter-related infections. *Ann Intern Med*. 2000;132(5):391–402
2. Burke JP. Infection control: a problem for patient safety. *N Engl J Med*. 2003;348(7):651–656
3. Richards MJ, Edwards JR, Culver DH, Gaynes RP; National Nosocomial Infections Surveillance System. Nosocomial infections in pediatric intensive care units in the United States. *Pediatrics*. 1999;103(4). Available at: www.pediatrics.org/cgi/content/full/103/4/e39
4. Pittet D, Tarara D, Wenzel RP. Nosocomial bloodstream infection in critically ill patients: excess length of stay, extra costs, and attributable mortality. *JAMA*. 1994;271(20):1598–1601
5. Pittet D, Wenzel RP. Nosocomial bloodstream infections: secular trends in rates, mortality, and contribution to total hospital deaths. *Arch Intern Med*. 1995;155(11):1177–1184
6. Urrea M, Pons M, Serra M, Latorre C, Palomeque A. Prospective incidence study of nosocomial infections in a pediatric intensive care unit. *Pediatr Infect Dis J*. 2003;22(6):490–494
7. Yogaraj JS, Elward AM, Fraser VJ. Rate, risk factors, and outcomes of nosocomial primary bloodstream infection in pediatric intensive care unit patients. *Pediatrics*. 2002;110(3):481–485
8. Grohskopf LA, Sinkowitz-Cochran RL, Garrett DO, et al. A national point-prevalence survey of pediatric intensive care unit-acquired infections in the United States. *J Pediatr*. 2002;140(4):432–438
9. Odetola FO, Moler FW, Dechert RE, VanDerElzen K, Chenoweth C. Nosocomial catheter-related bloodstream infections in a pediatric intensive care unit: risk and rates associated with various intravascular technologies. *Pediatr Crit Care Med*. 2003;4(4):432–436
10. Wisplinghoff H, Seifert H, Tallent SM, Bischoff T, Wenzel RP, Edmond MB. Nosocomial bloodstream infections in pediatric patients in United States hospitals: epidemiol-

ogy, clinical features and susceptibilities. *Pediatr Infect Dis J*. 2003;22(8):686–691

11. Aly H, Herson V, Duncan A, et al. Is bloodstream infection preventable among premature infants? A tale of two cities. *Pediatrics*. 2005;115(6):1513–1518
12. Elward AM, Hollenbeak CS, Warren DK, Fraser VJ. Attributable cost of nosocomial primary bloodstream infection in pediatric intensive care unit patients. *Pediatrics*. 2005;115(4):868–872
13. Pronovost P, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med*. 2006;355(26):2725–2732
14. Nowak JE, Brilli RJ, Lake MR, et al. Reducing catheter-associated bloodstream infections in the pediatric intensive care unit: business case for quality improvement. *Pediatr Crit Care Med*. 2010;11(5):579–587
15. Edwards JR, Peterson KD, Andrus ML, et al. National Healthcare Safety Network (NHSN) report, data summary for 2006, issued June 2007. *Am J Infect Control*. 2007;35(5):290–301
16. O'Grady N, Alexander M, Dellinger E, et al. Guidelines for the prevention of intravascular catheter-related infections. *MMWR Recomm Rep*. 2002;55(RR-10):1–26
17. Centers for Disease Control and Prevention. Available at: http://www.cdc.gov/nhsn/psc_da.html. Accessed October 3, 2011
18. Edwards JR, Peterson KD, Mu Y, et al. National Healthcare Safety Network (NHSN) report: data summary for 2006 through 2008, issued December 2009. *Am J Infect Control*. 2009;37(10):783–805
19. Miller MR, Griswold M, Harris JM II, et al. Decreasing PICU catheter-associated bloodstream infections: NACHRI's quality transformation efforts. *Pediatrics*. 2010;125(2):206–213
20. Centers for Disease Control and Prevention. CDC/NHSN surveillance definition of health care–associated infection and criteria for specific types of infections in the acute care setting. Available at: www.cdc.gov/ncidod/dhqp/pdf/nnis/NosInfDefinitions.pdf. Accessed July 29, 2010
21. Centers for Disease Control and Prevention. Central line-associated bloodstream infection (CLABSI) event. Available at: www.cdc.gov/nhsn/PDFs/pscManual/4PSC_CLABScurrent.pdf. Accessed October 3, 2011
22. Slonim AD, Kurtines HC, Sprague B, et al. The costs associated with nosocomial bloodstream infections in the pediatric intensive care unit. *Pediatr Crit Care Med*. 2001;2(2):170–174
23. Shekelle PG, Pronovost PJ, Wachter RM, et al. Advancing the science of patient safety. *Ann Intern Med*. 2011;154(10):693–696
24. Costello JM, Morrow DF, Graham DA, Potter-Bynoe G, Sandora TJ, Laussen PC. Systematic intervention to reduce central line associated bloodstream infection rates in a pediatric cardiac intensive care unit. *Pediatrics*. 2008;121(5):915–923
25. Wirtshafter DD, Pettit J, Kurtin P, et al. A statewide quality improvement collaborative to reduce neonatal central line–associated blood stream infections. *J Perinatol*. 2010;30(3):170–181
26. Soothill JS, Bravery K, Ho A, Macqueen S, Collins J, Lock P. A fall in bloodstream infections followed a change to 2% chlorhexidine in 70% isopropanol for catheter connection antisepsis: a pediatric single center before/after study on a hemopoietic stem cell transplant ward. *Am J Infect Control*. 2009;37(8):626–630
27. Ho KM, Litton E. Use of chlorhexidine-impregnated dressing to prevent vascular and epidural catheter colonization and infection: a meta-analysis. *J Antimicrob Chemother*. 2006;58(2):281–287
28. Timsit JF, Schwebel C, Bouadma L, et al. Chlorhexidine-impregnated sponges and less frequent dressing changes for prevention of catheter-related infections in critically ill adults: a randomized controlled trial. *JAMA*. 2009;301(12):1231–1241
29. Onder AM, Chandar J, Coakley S, Francoeur D, Abitbol C, Zilleruelo G. Controlling exit site infections: does it decrease the incidence of catheter-related bacteremia in children on chronic hemodialysis? *Hemodial Int*. 2009;13(1):11–18
30. Lin MY, Hota B, Khan YM, et al. Quality of traditional surveillance for public reporting of nosocomial bloodstream infection rates. *JAMA*. 2010;304(18):2035–2041
31. Niedner MF. The harder you look, the more you find: catheter associated bloodstream infection surveillance variability. *Am J Infect Control*. 2010;38(8):585–595

Reducing PICU Central Line–Associated Bloodstream Infections: 3-Year Results

Marlene R. Miller, Matthew F. Niedner, W. Charles Huskins, Elizabeth Colantuoni, Gayane Yenokyan, Michele Moss, Tom B. Rice, Debra Ridling, Deborah Campbell, Richard J. Brilli and the National Association of Children's Hospitals and Related Institutions Pediatric Intensive Care Unit Central Line –Associated Bloodstream Infection Quality Transformation Teams

Pediatrics 2011;128;e1077; originally published online October 24, 2011;
DOI: 10.1542/peds.2010-3675