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

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

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**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 for central line entry scrub or 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

**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

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

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**FINANCIAL DISCLOSURE:** The authors have indicated they have no financial relationships relevant to this article to disclose.
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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{18} 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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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>
<thead>
<tr>
<th>Insertion bundle</th>
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<tbody>
<tr>
<td>Hand washing before procedure</td>
</tr>
<tr>
<td>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)</td>
</tr>
<tr>
<td>No iodine skin preparation; no iodine ointment at insertion site</td>
</tr>
<tr>
<td>Prepackaged or filled insertion cart, tray, or box</td>
</tr>
<tr>
<td>Insertion checklist (with staff empowerment to stop nonemergency procedure if sterile insertion practice not being followed)</td>
</tr>
<tr>
<td>Full sterile barrier for providers and patient</td>
</tr>
<tr>
<td>Insertion training for all providers (eg, slides and video)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maintenance bundle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily assessment of whether catheter is needed</td>
</tr>
<tr>
<td>Catheter site care</td>
</tr>
<tr>
<td>No iodine ointment</td>
</tr>
<tr>
<td>Chlorhexidine scrub to site with dressing changes (30-s scrub and 30-s air dry)</td>
</tr>
<tr>
<td>Change gauze dressings every 2 d unless soiled, dampened, or loosened (CDC recommended)</td>
</tr>
<tr>
<td>Change clear dressing every 7 d unless soiled, dampened, or loosened (CDC recommended)</td>
</tr>
<tr>
<td>Prepackaged dressing change kit (each unit to define package contents)</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Catheter hub/cap/tubing care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replace administration sets, including add-on devices, no more frequently than every 72 h unless soiled or suspected to be infected</td>
</tr>
<tr>
<td>Replace tubing used to administer blood, blood products, or lipids within 24 h after initiation of infusion (CDC recommended)</td>
</tr>
<tr>
<td>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)</td>
</tr>
<tr>
<td>Prepackaged cap change kit/cart/central location (elements designated by local institution)</td>
</tr>
</tbody>
</table>
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 50-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. 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 (non-

### 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 transplants, and extracorporeal membrane oxygenation.

### Table 2 Characteristics of 29 Participating ICUs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of unit</td>
<td></td>
</tr>
<tr>
<td>PICU</td>
<td>9 (31)</td>
</tr>
<tr>
<td>PICU/cardiac ICU</td>
<td>18 (62)</td>
</tr>
<tr>
<td>Cardiac ICU</td>
<td>2 (7)</td>
</tr>
<tr>
<td>No. of beds</td>
<td></td>
</tr>
<tr>
<td>10–16</td>
<td>12 (41)</td>
</tr>
<tr>
<td>17–27</td>
<td>13 (45)</td>
</tr>
<tr>
<td>28–36</td>
<td>4 (14)</td>
</tr>
<tr>
<td>Annual mean PICU length of stay (4.6–6.3 d)</td>
<td></td>
</tr>
<tr>
<td>2.7–4.5 d</td>
<td>14 (48)</td>
</tr>
<tr>
<td>4.6–6.3 d</td>
<td>12 (41)</td>
</tr>
<tr>
<td>6.4–9.6 d</td>
<td>3 (10)</td>
</tr>
<tr>
<td>Yearly total of PICU patient-days</td>
<td></td>
</tr>
<tr>
<td>2100–5700</td>
<td>10 (34)</td>
</tr>
<tr>
<td>5701–6500</td>
<td>10 (34)</td>
</tr>
<tr>
<td>6501–8700</td>
<td>9 (31)</td>
</tr>
<tr>
<td>No. of ICU admissions in 2005</td>
<td></td>
</tr>
<tr>
<td>300–600</td>
<td>10 (34)</td>
</tr>
<tr>
<td>601–1800</td>
<td>15 (52)</td>
</tr>
<tr>
<td>1801–2400</td>
<td>4 (14)</td>
</tr>
<tr>
<td>Institution is level 1 trauma center</td>
<td>19 (66)</td>
</tr>
<tr>
<td>Institution performs solid-organ transplants</td>
<td>25 (86)</td>
</tr>
<tr>
<td>Institution performs bone marrow transplants</td>
<td>21 (72)</td>
</tr>
<tr>
<td>ICU performs extracorporeal membrane oxygenation</td>
<td>26 (90)</td>
</tr>
</tbody>
</table>
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 \(~11\% \text{ per month (95\% CI: 3\%–18\% decrease per month; } P = .006 \)). 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 \(~15\% \text{ in January 2008 because of the change in the NHSN definition for CLA-BSIs; however this decrease was not statistically significant ( } P = .448 \)). 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

![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.)
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. 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 measurable 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. 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. 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. Given the manifolds 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. Similar gradual decreases in pediatric CLA-BSI rates were reported for a single cardiac PICU and a large cohort of NICUs. 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, adoption 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 the context of our findings. Sec- ond, 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.


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