Decreasing PICU Catheter-Associated Bloodstream Infections: NACHRI's Quality Transformation Efforts

WHAT'S KNOWN ON THIS SUBJECT: CA-BSIs are a significant source of morbidity, mortality, and added medical costs to hospitalized adult and pediatric patients. Despite these data, strategies for reducing health care complications such as pediatric CA-BSIs have received relatively little attention.

WHAT THIS STUDY ADDS: In contrast with adult ICU care, maximizing insertion-bundle compliance alone cannot help PICUs to eliminate CA-BSIs. Instead, the main drivers for additional reductions in pediatric CA-BSI rates seem to be issues surrounding daily maintenance care for central lines.

abstract

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OBJECTIVE: Despite the magnitude of the problem of catheter-associated bloodstream infections (CA-BSIs) in children, relatively little research has been performed to identify effective strategies to reduce these complications. In this study, we aimed to develop and evaluate effective catheter-care practices to reduce pediatric CA-BSIs.

STUDY DESIGN AND METHODS: Our study was a multi-institutional, interrupted time-series design with historical control data and was conducted in 29 PICUs across the United States. Two central venous catheter–care practice bundles comprised our intervention: the insertion bundle of pediatric-tailored care elements derived from adult efforts and the maintenance bundle derived from the Centers for Disease Control and Prevention recommendations and expert pediatric clinician consensus. The bundles were deployed with quality-improvement teaching and methods to support their adoption by teams at the participating PICUs. The main outcome measures were the rate of CA-BSIs from January 2004 to September 2007 and compliance with each element of the insertion and maintenance bundles from October 2006 to September 2007.

RESULTS: Average CA-BSI rates were reduced by 43% across 29 PICUs (5.4 vs 3.1 CA-BSIs per 1000 central-line-days; $P < .0001$). By September 2007, insertion-bundle compliance was 84% and maintenance-bundle compliance was 82%. Hierarchical regression modeling showed that the only significant predictor of an observed decrease in infection rates was the collective use of the insertion and maintenance bundles, as demonstrated by the relative rate (RR) and confidence intervals (CIs) (RR: 0.57 [95% CI: 0.45–0.74]; $P < .0001$). We used comparable modeling to assess the relative importance of the insertion versus maintenance bundles; the results showed that the only significant predictor of an infection-rate decrease was maintenance-bundle compliance (RR: 0.41 [95% CI: 0.20–0.85]; $P = .017$).

CONCLUSIONS: In contrast with adult ICU care, maximizing insertion-bundle compliance alone cannot help PICUs to eliminate CA-BSIs. The main drivers for additional reductions in pediatric CA-BSI rates are issues that surround daily maintenance care for central lines, as defined in our maintenance bundle. Additional research is needed to define the optimal maintenance bundle that will facilitate elimination of CA-BSIs for children. *Pediatrics* 2010;125:206–213

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KEY WORDS

bloodstream infections, children, catheter-associated bloodstream infections, nosocomial infections, pediatric intensive care unit, hospital-acquired infections

ABBREVIATIONS

CA-BSI—catheter-associated bloodstream infection
RR—relative rate
CI—confidence interval
CDC—Centers for Disease Control and Prevention
NACHRI—National Association of Children's Hospitals and Related Institutions
CVL—central venous line

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Catheter-associated bloodstream infections (CA-BSIs) are a significant cause of morbidity, mortality, and added medical costs to hospitalized adult and pediatric patients.[1–11] According to the National Nosocomial Infection Surveillance System established by the Centers for Disease Control and Prevention (CDC), the pooled mean in 2004 among 54 PICUs was 6.6 CA-BSIs per 1000 catheter-days, higher than in many adult ICUs.[12] More recent estimates that included 36 PICUs have shown a pooled mean rate of 5.3 CA-BSIs per 1000 catheter-days.[13] Despite these data, strategies to reduce health care complications such as pediatric CA-BSIs have received relatively little attention.

CA-BSIs in adult ICUs have been nearly eliminated by applying a multifaceted intervention[14–17] that is now used broadly throughout the United States and the world. Whether these findings and interventions apply to children is not known.

Children who receive care in PICUs have unique, albeit not thoroughly researched, risk factors for CA-BSIs compared with adult patients. These differences include a less-clear protective effect of central lines in the jugular or subclavian veins, as opposed to the femoral veins, and the presence of underlying genetic syndromes and congenital malformations.[18–20] In addition, pediatric providers use patient central lines differently. For example, consistent anecdotal reports have shown providers to have a greater reliance on central lines to obtain needed blood samples or to keep the lines in place longer to ensure secure venous access in an emergency. The National Association of Children's Hospitals and Related Institutions (NACHRI) developed a quality-improvement collaborative, composed of 29 PICUs, to identify and test the impact of pediatric-specific catheter-care practices in reducing pediatric CA-BSI rates.

METHODS

Study Design, Setting, Participants, and Objectives

Twenty-seven NACHRI member hospitals agreed to work collaboratively to reduce the CA-BSI rates among their 29 PICUs. The study design was a multi-institutional, interrupted time-series design that included historical control data from each of the 29 PICUs from January 2004 to August 2006. With a goal of eliminating CA-BSIs attributed to the PICU, the collaborative set interim first-year goals of a 50% decrease in CA-BSI rates by reliably using the collaborative insertion bundle for 90% of central line insertions and by reliably performing the collaborative maintenance bundle for 70% of all central line catheter-maintenance care.

As part of their participation in the collaborative, each team committed a senior PICU leader/physician champion to support and promote the unit team. The 2 to 3 additional team members for each site included quality-improvement leaders, infectious disease physicians, PICU nursing leaders, and/or infection-control professionals. The PICU teams participated in 4 face-to-face learning workshops in the first year, monthly conference calls, and monthly data collection and submission. Each PICU team, using quality-improvement methods of small tests of change, tested and implemented changes to make their care practices commensurate with the collaborative's recommended central line insertion and maintenance-care practices. From October 2006 through September 2007, the teams engaged in intensive efforts to reduce PICU CA-BSI rates by implementing the insertion and maintenance-care bundles. Each PICU team consulted with its respective institutional review board (IRB) regarding collaborative participation and received either IRB approval or a determination that the effort did not need IRB review.

Interventions

Our study involved 2 central line care bundles, one focused on insertion practices and one focused on maintenance practices (Table 1). The insertion bundle included evidence-based procedures recommended by the CDC that have been proven to be effective in adult patients or in a single institutional PICU.[16,21,22] Contrary to adult CA-BSI efforts, our bundle did not discourage the use of the femoral site, because this can often be the most convenient or optimal insertion site for children, and the evidence of increased infection risk with femoral sites is not definitive for pediatric patients.[12,23–25] The maintenance bundle was created by using some of the pertinent CDC guidelines; however, consensus of mostly expert pediatric physicians and nurses from approximately 20 children's institutions were involved in the development of this effort because of the relative paucity of more rigorous evidence on an effective maintenance bundle.[14,21]

Measures and Data

Data were collected by using insertion-bundle and maintenance-bundle compliance as the 2 process measures. Each PICU team self-monitored all central-line insertions that occurred in the PICU and submitted data on compliance with each insertion-bundle element for all of the insertions that occurred each month. Once each week, each PICU team audited all of the central lines to check for compliance with each element of the maintenance bundle. The insertion-bundle and maintenance-bundle audit data were recorded each month by each PICU and entered into the collaborative data-

TABLE 1 Central Line Catheter–Care Bundles

Insertion bundle
Wash hands before the procedure.
For all children aged ≥2 mo, use chlorhexidine gluconate to scrub the insertion site for 30 s for all areas except the groin, which should be scrubbed for 2 min. Scrubbing should be followed by 30 to 60 s of air drying.
No iodine skin prep or ointment is used at the insertion site.
Prepackage or fill the insertion cart, tray, or box including full sterile barriers
Create an insertion checklist, which empowers staff to stop a nonemergent procedure if it does not follow sterile insertion practices.
Use only polyurethane or Teflon catheters.[a]
Conduct insertion training for all care providers, including slides and video.
Maintenance bundle
Assess daily whether catheter is needed.
Catheter-site care
No iodine ointment.
Use a chlorhexidine gluconate scrub to sites for dressing changes (30-s scrub, 30-s air-dry).
Change gauze dressings every 2 d unless they are soiled, dampened, or loosened.[a]
Change clear dressings every 7 d unless they are soiled, dampened, or loosened.[a]
Use a prepackaged dressing-change kit or supply area
Catheter hub, cap, and tubing care
Replace administration sets, including add-on devices, no more frequently than every 72 h unless they are soiled or suspected to be infected.
Replace tubing that is used to administer blood, blood products, or lipids within 24 h of initiating infusion.[a]
Change caps no more often than 72 h (or according to manufacturer recommendations); however, caps should be replaced when the administration set is changed.[a]
The prepackaged cap-change kit, or supply area elements to be designated by the local institution.

[a] These procedures are according to the CDC recommendations.

base. Compliance for both bundles was assessed as all or none, meaning that each patient's insertion or maintenance event had to comply with all of the elements of the respective bundle to be considered compliant.

Our outcome measure was the monthly PICU CA-BSI rate, defined as CA-BSI cases per 1000 central-line-days. The number of CA-BSI cases and the monthly total of central-line-days per PICU were collected by trained, hospital-based, infection-control practitioners in accordance with CDC definitions.[21]

Analysis and Interpretation

Monthly and quarterly data pertaining to the CA-BSI collaborative were recorded and analyzed from January 2004 through September 2007. The entire collaborative effort was subdivided into 3 time periods for the analysis. The baseline period was from January 2004 through September 2006, quarters 1 through 11. A ramp-up period was defined as the initial 3 months of collaborative interventions from October 2006 until December 2006, when there was variation between the units regarding how many of the bundle elements were being fully implemented. A stable-effect period ranged from January 2007 through September 2007 during sustained and comprehensive CA-BSI intervention efforts by all of the PICU teams.

To examine the data and account for the clustering effect within the individual PICUs, we used hierarchical modeling including marginal generalized linear models with log-links, negative binomial distributions, and working autoregressive correlation structures. These models were fit by using generalized estimating equations with robust variance estimation.[26] The analytic model allowed the CA-BSI rate to change as a function of time within each period (different temporal slopes within the baseline, ramp-up, and stable-effects periods); the log-link in the generalized linear models implied that exponentiated coefficients were interpreted as relative rates (RRs), which were relative increases or decreases above or below the last quarter's rate, similar to a relative risk. Specifically, the model estimated the RR (increase or decrease) of CA-BSIs per quarter during the baseline period, the RR of CA-BSIs comparing the ramp-up period to the last quarter of the baseline period, and the RR of CA-BSIs per quarter during the stable-effects period. An additional simplified model was examined to estimate a single CA-BSI rate during each of the 3 periods (baseline, ramp-up, and stable-effects) and to compare those rates. The use of the simplified model assuming a single CA-BSI rate during each of the 3 periods was considered acceptable given that within each period, the CA-BSI rate did not significantly change over time. Models were adjusted for geographic region, average length of stay, and bed capacity to account for any unpredicted regional variations in care and to attempt to account for any PICU-specific severity of patient illness. Nonlinear relationships were explored by using the lowess smoothing functions and splines.[27,28]

Hierarchical regression modeling was also used to examine individual compliance effects (either insertion or maintenance) after adjusting for covariables and the alternate compliance variable.[29]

Missing data in our analyses were exclusively confined to the baseline precollaborative period (January 2004 to September 2006) and encompassed 18.6% of baseline data. To examine the effects of the missing data, we ran 2 sensitivity analyses models by imputing data for each missing data point. All of the results were similar in estimates and statistical significance to the all-observable analyses reported here.[30–33]

All analyses were conducted by using SAS 9.1 (SAS Institute, Inc, Cary, NC), and statistical process control charts, including U charts, were also used in the preliminary analyses to examine whether the observed differences were a special-cause variation or a common-cause variation.[34]

RESULTS

Table 2 provides the characteristics of the 29 pediatric PICUs enrolled in our NACHRI PICU CA-BSI collaborative. Overall, most of the PICUs were mixed pediatric and cardiac PICUs, with 2 being solely pediatric cardiac ICUs. The majority of sites had level 1 trauma centers and performed solid-organ transplants, bone marrow transplants, and extracorporeal membrane oxygenation.

TABLE 2 Characteristics of the 29 Participating ICUs

Characteristic	*n*
Unit type	
PICU	9
PICU/CICU	18
CICU	2
Beds, *n*	
10–16	12
17–27	13
28–36	4
Annual PICU length of stay, mean, d	
2.7–4.5	14
4.6–6.3	12
6.4–9.6	3
Yearly total of PICU patient days, d	
2100–3600	10
3700–6200	10
6300–8700	9
ICU annual admissions in 2005	
300–899	10
900–1700	15
1800–2400	4
Institution is level 1 trauma center	
Yes	19
No	10
Institution performs solid-organ transplants	
Yes	25
No	4
Institution performs bone marrow transplants	
Yes	21
No	7
ICU performs ECMO	
Yes	26
No	3

CICU indicates cardiac ICU; ECMO, extracorporeal membrane oxygenation.

The average baseline CA-BSI rate for the 29 PICUs, in aggregate, was 5.4 CA-BSIs per 1000 central-line-days. After initiation of the interventions, the rate began to decrease in the ramp-up period (4.3 CA-BSIs per 1000 central-line-days) and decreased to an average stable-effect rate of 3.1 CA-BSIs per 1000 central-line-days. These results translate into a significant difference between the baseline CA-BSI rate and the steady-state stable-effect period CA-BSI rate, with a decrease from 5.4 (95% confidence interval [CI]: 4.5–6.4–3.1 and 2.4–4.0, respectively; $P < .0001$).

In terms of the stated first-year goals of the NACHRI PICU CA-BSI collaborative, the 29 PICUs achieved a 43% reduction in CA-BSI rates. By the end of the first year, the collaborative came close to achieving the insertion-bundle compliance goal with 84% sustained compliance and met the maintenance-bundle compliance goal with 82% sustained compliance.

The 29 PICUS reported 324 CA-BSI events during the 12-month postintervention study period (95 205 total central-line-days.).

We used hierarchical cluster-analysis regression modeling and adjusted for the ICU region and PICU demographics (average length of stay and bed capacity). The only significant predictor of the observed decrease in CA-BSI rates was the collective interventions that were used in this collaborative, namely the insertion and maintenance bundles, during the stable-effect period (RR: 0.57 [95% CI: 0.45–0.74]; $P <$ .0001). Given the downward trend in CA-BSI rates in the baseline data, a more-stringent sensitivity analysis, assuming that the baseline period CA-BSI rate was actually decreasing as opposed to being constant, was conducted to account for this trend. Nearly identical results were found (RR: 0.618 [95% CI: 0.47–0.82]; $P < .001$).

To begin exploring which of the bundles had the greatest influence on the observed CA-BSI rate decrease, Fig 1 shows the lowess smoothing line and 95% CIs of the aggregate data from the 29 PICUS for both precollaborative and collaborative CA-BSI rates, as well as the lowess smoothing lines and 95%

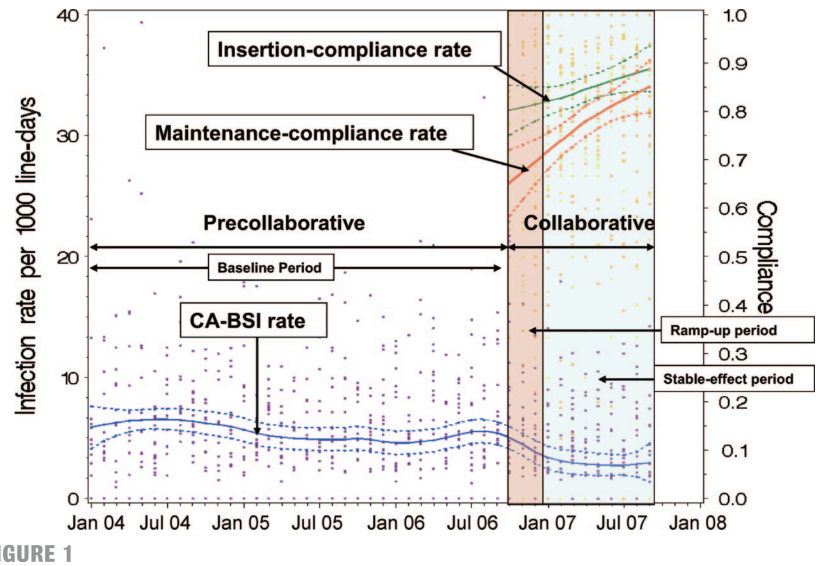

FIGURE 1
Data from 29 PICUs showing the rates of CA-BSIs and insertion and maintenance compliance and 95% CIs in the precollaborative and collaborative periods.

CIs of the average compliance with the insertion and maintenance bundles in the collaborative period across all 29 PICUs. It is noteworthy that the apparent wide variation in CA-BSI rates is largely a result of variation in the denominator size among the 29 PICUs, from lows of 60 central-line-days per month to highs of 500 central-line-days per month.

Additional analysis to determine the relative importance of insertion-bundle compliance compared with maintenance-bundle compliance was performed by using hierarchical cluster modeling. After adjusting for region and PICU demographics, the only significant predictor of the CA-BSI rate decrease was maintenance-bundle compliance (RR: 0.41 [95% CI: 0.20–0.85]; $P = .017$).

DISCUSSION

In this PICU CA-BSI collaborative, we demonstrated that reliably implementing a pediatric-specific central-line insertion bundle and a new pediatric central-line maintenance bundle can achieve and sustain significant decreases in pediatric CA-BSI rates in the PICU setting. In contrast with adult ICU care, maximizing insertion-bundle compliance alone cannot help PICUs eliminate CA-BSIs. Instead, the main drivers for further reducing pediatric CA-BSI rates seem to be issues that surround daily maintenance care for central lines, an attribute of bedside nursing care and practice.

To our knowledge, this study is the first to clearly articulate the differential impact of insertion-related practices versus maintenance-related practices on CA-BSI rates in either adult or pediatric populations.[15–17] Indeed, researchers have emphasized that practices related solely to the insertion of central lines are able, in adult patients, to significantly reduce CA-BSIs.[15,16] In our study, the main driver to reduce CA-BSIs was a care bundle focused on maintenance practices, not on insertion practices.

Our analyses should not be interpreted to mean that evidence-based practices for CVL insertions with children should be abandoned. It is much more likely that the 29 PICUs in this collaborative had already maximized the impact of improving central-line insertion practices in the precollaborative period. For several years now, the health care industry has been extensively focused on insertion practices, and every PICU in our collaborative had already changed many of its insertion-related practices, on the basis of these national pressures, in the precollaborative period. In addition, our data suggest that additional reductions in CA-BSI rates will more likely be achieved by focusing attention on the day-to-day handling of central lines and not by additional work on adherence to evidence-based insertion practices. The data in Fig 1 support this assertion. At the onset of this collaborative, adherence to the ideal insertion practices was already higher than 80%. In contrast, adherence to the ideal maintenance practices at the onset of this collaborative was approximately 65%.

Our study also highlights the importance of multidisciplinary teams to address CA-BSIs and the ideal nature of collaborative models for improving pediatric care. Although nurses are clearly involved in helping to ensure adherence to ideal central-line insertion practices, this nursing role is largely a "double-check" function. In contrast, all of the clinical elements in our maintenance bundle comprise direct nursing behaviors in the day-to-day care of patients. The relationship between hands-on practices of physicians with insertion and hands-on practices of nurses for the daily care of central lines epitomizes the intertwined team nature of care and the dependence on both disciplines to prevent harm to patients from CA-BSIs. Furthermore, this study showcases the strength and value of collaborative multidisciplinary improvement efforts for pediatric care.

We recognize that there are several limitations to this study. First, we did not demonstrate that this intervention can sustain a reduction in CA-BSI rates over several years. Given the track record to date of this intervention across 29 ICUs and new findings regarding the importance of the maintenance bundle, we believe that it is important to disseminate this information sooner rather than later. Our intention is to focus attention on the need for more research to further identify optimal central-line maintenance-care practices. Second, the definition of CA-BSIs as set by the CDC does not take into account the number and timing of central lines. For example, a patient with 5 simultaneous central lines over a period of 2 weeks, versus a patient with 5 sequential central lines over a period of 2 weeks, versus a patient with 1 continuous central line over a period of 2 weeks are all counted as the same number of central-line-days and assumed to be at risk for a CA-BSI, according to the CDC. These definitions, however, are standardized at all institutions that report CA-BSI data to the CDC, effectively eliminating these definitional issues as a problem when comparing institutions. Third, the 29 ICUs within the collaborative are large PICUs with an extremely ill patient population. However, the interventions described in this study could be easily implemented in other facilities regardless of their size or patient acuity. The core ideas behind these interventions revolve around educating caretakers about effective practice techniques for central-line insertion and maintenance, centralizing equipment so that adherence to best practices is easy, reliably implementing and measuring compliance with best practices, using real-time data to drive change, and team-building including nurse empowerment. All of these attributes are applicable in any ICU setting.

CONCLUSIONS

CA-BSIs are a preventable cause of patient harm to critically ill children. Our pediatric-specific central line insertion and maintenance bundles, which combine evidence-based guidelines with human-factors principles to reduce complexity and enhance implementation, have demonstrated that CA-BSIs are preventable for children. In contrast with adult ICU care, maximizing insertion-bundle compliance alone cannot help PICUs to eliminate CA-BSIs. Instead, the main driver for additional reductions in pediatric CA-BSI rates seems to involve issues surrounding daily maintenance care for central lines, as defined by our maintenance bundle. Although reliable implementation of best practices for central-line insertion and maintenance can significantly decrease PICU CA-BSIs, additional research is still needed to determine the optimal maintenance bundle that will facilitate elimination of CA-BSIs in all children who require short- or long-term central venous access.

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