The Impact of Bedside Behavior on Catheter-Related Bacteremia in the Intensive Care Unit

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Hypothesis: The success of an educational program in July 1999 that lowered the catheter-related bloodstream infection (CRBSI) rate in our intensive care unit (ICU) 3-fold is correlated with compliance with "best-practice" behaviors.

Design: Before-after trial.

Setting: Surgical ICU in a referral hospital.

Patients: A random sample underwent bedside audits of central venous catheter care (n=187). All ICU admissions during a 39-month period (N=4489) were prospectively followed for bacteremia.

Interventions: On the basis of audit results in December 2000, a behavioral intervention was designed to improve compliance with evidenced-based guidelines of central venous catheter management.

Main Outcome Measures: Compliance with practices known to decrease CRBSI. Secondary outcome was CRBSI rate on all ICU patients.

Results: Multiple deficiencies were identified on bedside audits 18 months after the previous educational program. After the implementation of a separate behavioral intervention in July 2001, a second set of bedside audits in December 2001 demonstrated improvements in documenting the dressing date (11% to 21%; $P<.001$) and stopcock use (70% to 24%; $P<.001$), whereas nonsignificant trends were observed in hand hygiene (17% to 30%; $P>.99$) and maximal sterile barrier precautions (50% to 80%; $P=.29$). Appropriate practice was observed before and after the behavioral intervention in catheter site placement, dressing type, absence of antibiotic ointment, and proper securing of central venous catheters. Thirty-two CRBSIs occurred in 9353 catheter-days 24 months before the behavioral intervention compared with 17 CRBSIs in 6152 catheter-days during the 15 months after the intervention (3.4/1000 to 2.8/1000 catheter-days; $P=.40$).

Conclusions: Although a previous educational program decreased the CRBSI rate, this was associated with only modest compliance with best practice principles when bedside audits were performed 18 months later. A behavioral intervention improved all identified deficiencies, leading to a nonsignificant decrease in CRBSIs.

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APPROXIMATELY 250 000 catheter-related bloodstream infections (CRBSIs) occur annually in the United States, many of which are preventable with appropriate adherence to evidenced-based guidelines in infection control.[1] Although the attributable mortality due to a CRBSI is controversial (range, 0%-35%), these infections cause excess morbidity and length of stay across all studies and represent a major public health concern.[2-7] The marginal cost of a primary bacteremia is \$25 000,[1] but has been estimated to be as high as \$56 167 in 1998 dollars in intensive care unit (ICU) patients.[8]

Although multiple strategies for decreasing CRBSIs exist, educating health care workers has been demonstrated to be an efficient, cost-effective technique to decrease infection rates.[9-14] An example of this is a previously reported experience with an educational program aimed primarily at nurses in the surgical ICU at Barnes-Jewish Hospital, St Louis, Mo, a 1000-bed primary and tertiary care hospital.[9] From January 1, 1998, through June 30, 1999, our infection rate was 10.8/1000 catheter-days, substantially higher than the national average in other surgical, trauma, and burn ICUs at that time of 5.8/1000 catheter-days, according to data from the National Nosocomial Infections Surveillance (NNIS) system of the Centers for Disease Control and Prevention, Atlanta, Ga. Because our rates were nearly double the national average, a comprehensive educational program was constructed in July 1999 aimed at preventing CRBSIs.

The centerpiece of this educational program was a self-study module covering a broad range of topics related to CRBSIs. Before taking the module and again after taking it, nurses were required to take a 20-question multiple choice examination to test their knowledge on the material covered. Test scores improved from a mean of 78% correct before this educational program to 89% immediately after its conclusion. This improvement in knowledge was accompanied by a 3-fold decrease in CRBSIs from 10.8/1000 catheter-days from January 1998 to June 1999, before the educational program, to 3.7/1000 catheter-days in the 18 months after its completion.

Despite the success of this and other programs in decreasing CRBSIs, it was unclear whether the many lessons being taught resulted in improved practice, since behavior was not monitored after the implementation of the educational program. In fact, beyond the decrease in infection rate (which may have been due to unrelated factors), there was no proof that didactic teaching translated into compliance with "best-practice" principles such as anatomic site of catheter insertion (subclavian preferred),[15-20] appropriate hand hygiene,[21-26] maximal sterile barrier precautions,[19,27,28] type of catheter site dressing,[1,29,30] avoidance of antibiotic ointment,[1,19,31-33] and presence or absence of stopcocks (absence of stopcocks on any tubing other than pressure tubing being preferred).[34] We therefore sought to determine the bedside behavior patterns being used 18 months after our previous educational program through the use of bedside audits. Since these audits showed a discrepancy between actual practice and best practice, we subsequently designed and implemented a behavioral intervention to see whether we could further improve bedside practice patterns.

METHODS

STUDY LOCATION AND PATIENT ENROLLMENT

All patients admitted to the surgical ICU at Barnes-Jewish Hospital at Washington University School of Medicine between January 1, 1998, and September 30, 2002 , were prospectively followed by an infection control team for the presence of CRBSI (infection rates, but not bedside behavior patterns, from 1998 to 2000 have been published elsewhere[9]). The surgical ICU admits approximately 1400 patients a year with an average length of stay of 4.3 days and expanded from 18 beds at the start of the study to 24 beds at its conclusion. Patient demographics were similar throughout the course of the study.

Bloodstream infections were classified as primary or secondary on the basis of NNIS definitions.[35] We defined a CRBSI as (1) a microorganism isolated from a blood culture not related to distant infection or (2) a fever of greater than 38.5°C, chills, or hypotension and either a common skin contaminant (typically a coagulase-negative *Staphylococcus* species) isolated from 2 blood cultures drawn at separate times within 24 hours unrelated to distant infection or isolated from a blood culture in a patient with a CVC and treated by the attending ICU physician with a full course of antibiotics. Bloodstream infections with documented distant infection with the same pathogen were characterized as secondary bacteremias. The data presented herein pertain to CRBSIs only. The BSI rates of the ICU, and how these compare with national rates using NNIS data, were presented at multidisciplinary staff meetings on a monthly basis. The study was approved by the Human Studies Committee at Washington University School of Medicine.

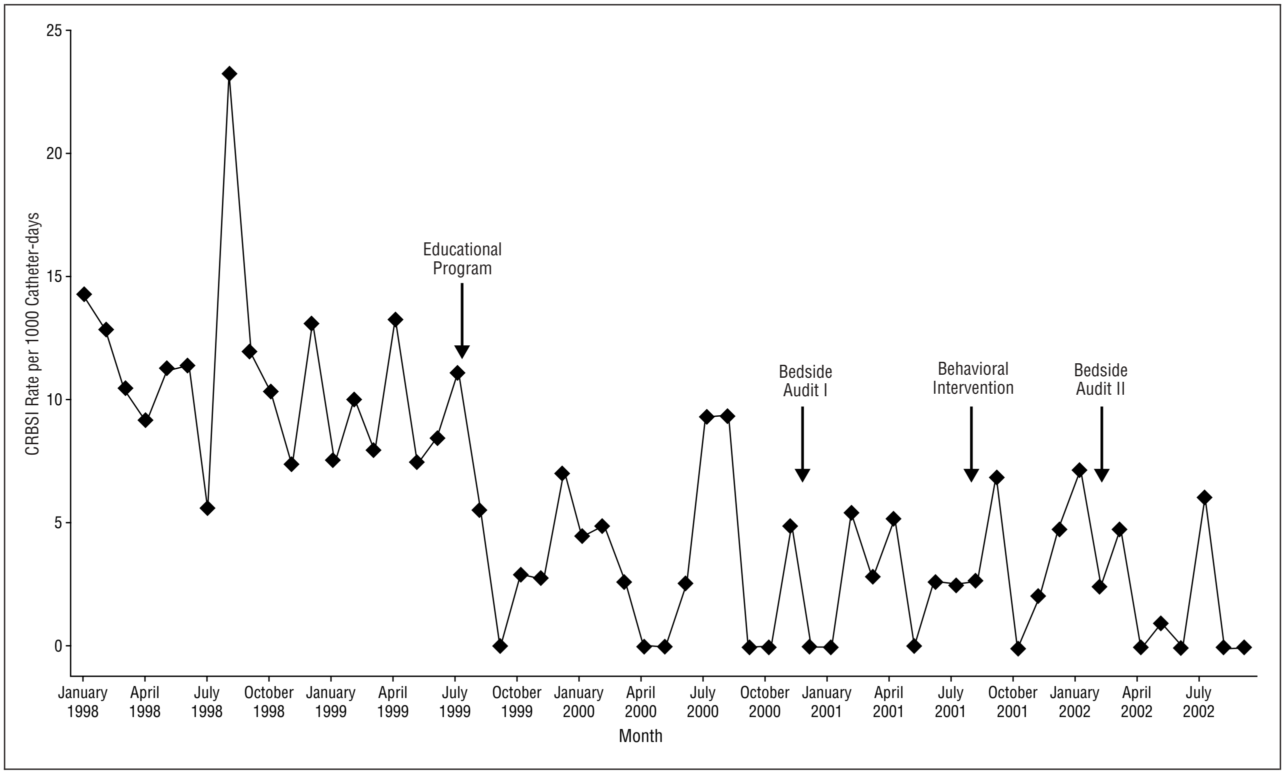
STUDY DESIGN

A multidisciplinary team with physicians, an infection control specialist, nurses, a pharmacist, and a quality improvement specialist met on several occasions to form flowcharts of evidence-based best practice, detailing maintenance and insertion of CVCs. General areas of best practice included site of catheter insertion (subclavian preferred to internal jugular, preferred to femoral),[16-21] appropriate hand hygiene (hand washing or use of alcohol foam),[22-27] use of maximal sterile barrier precautions for CVC insertion (defined as mask, cap, sterile gloves, gown, and large drape),[20,28,29] type of catheter site dressing,[1,30,31] avoidance of antibiotic ointment,[1,20,32-34] and presence or absence of stopcocks (absence of stopcocks on any tubing other than pressure tubing being preferred).[35] We used this literature-based determination of risk factors involved in catheter infections to develop an audit tool to determine whether randomly checked CVCs were properly maintained or whether new insertions were performed under sterile conditions. Basic demographic information was also included on the audits. Three-team members (C.S.S., M.E.S., and S.J.E.) performed the first set of these observations from November 2000 through January 2001 (**Figure**) without the knowledge of the nursing and resident team caring for the patients. A substantially smaller number of CVC insertions were observed because of (1) the difficulty in auditing an insertion without the knowledge of the person placing the line (which could alter their behavior) and (2) the length of time it takes to insert a line compared with the much shorter time it takes to observe a dressing.

After these bedside audits, a behavioral intervention was designed. This behavioral intervention is fully distinct from the previously published educational program outlined in the introduction. The first set of bedside audits took place 18 months after the previous educational program, and based on the results of these audits, the behavioral intervention took place 24 months after the previous educational program (Figure).

The behavioral intervention stressed compliance with all facets of best practice of CVC maintenance and insertion, as opposed to being targeted to deficiencies noted in the first set of audits. The intervention was multifactorial. Pictures demonstrating each step of CVC maintenance (aimed at nursing staff) and insertion (aimed at physicians) were placed at every patient's bed, throughout the ICU, and in the manual each resident receives when they rotate through the ICU. Lectures and hands-on demonstrations were given to nurses as part of their annual skills sessions by two of us (C.S.S. and M.E.S.). Lectures were given to the entire resident staff in the departments of surgery and emergency medicine by one of us (C.M.C.), and monthly lectures were given to all residents rotating through the ICU. To assess the success of the behavioral intervention, a second set of bedside audits was performed from November 2001 through February 2002 (Figure), 5 to 8 months after its implementation. The Figure demonstrates the timeline of the previous educational program, the first set of bedside audits, the subsequent behavioral intervention, and the second set of bedside audits.

Throughout the 39 months after the previous educational program, CVC maintenance and site care were performed by registered nurses only. The CVCs were placed by residents from the departments of surgery (postgraduate years 1 and 2), anesthesiology (postgraduate years 2 and 3), and emergency medicine (postgraduate year 2) as part of their 4-week rotations and a full-time nurse practitioner. The CVC inser-



The catheter-related bloodstream infection (CRBSI) rate per 1000 catheter-days. Arrows identify timing of the previous educational program, subsequent behavioral intervention, and bedside audits of central venous catheter care before (I) and after (II) the behavioral intervention.

tion was supervised by surgery, anesthesiology, or pulmonary/critical care fellows or by ICU attending staff. Only 1 of the 12 attending physicians in the ICU (C.M.C.) was involved in the task force that developed the behavioral intervention, so it is unlikely that attending practice was substantially altered on the basis of knowledge of the outcomes being evaluated. The CVCs were not routinely changed over guidewires at any time during the study.

STATISTICAL ANALYSIS

Data were analyzed using GraphPad Prism 3.0 software (GraphPad Software, Inc, San Diego, Calif). Behaviors on the audit sheet were marked as yes or no (eg, did the person inserting the CVC use appropriate hand hygiene before insertion?). Audit data from before and after the behavioral intervention were compared using the Fisher exact test. The incidence of CRBSI before and after the behavioral intervention was compared using the Mann-Whitney test. We considered *P* values of less than .05 to be statistically significant.

Table 1. Characteristics of Patients Undergoing Audit for CVC Maintenance

	Before Behavioral Intervention*	After Behavioral Intervention†
Male, %	49.4	56.9
Age, mean, y	54.5	57.4
Contact isolation, %	25.2	25.0
Length of time catheter in place, mean, d	6.0	6.3
Duration of CVC, %		
<7 d	62.9	57.8
7-10 d	29.4	35.9
>10 d	7.7	6.3

Abbreviation: CVC, central venous catheter.
*Percentages are based on 171 CVCs in 99 patients.
†Percentages are based on 138 CVCs in 72 patients.

RESULTS

BEDSIDE PRACTICE AFTER THE PREVIOUS EDUCATIONAL PROGRAM

The first set of bedside audits on CVC maintenance was performed on 171 CVCs in 99 randomly selected patients from November 2000 through January 2001 (Figure, **Table 1**, and **Table 2**). Audits were also performed on 6 randomly selected CVC insertions at the same time (**Table 3**). The results of these bedside observations demonstrate that low infection rates attributed to the previous educational program correlated only modestly with compliance with best practice, with deficiencies evident in CVC maintenance and insertion. On the maintenance audits, specific problems were identified in placing a proper, legible date on the catheter dressing or electronically charting this in the patient's computerized medical record (performed in only 11% of lines audited) and in excessive use of stopcocks outside of pressure tubing in 70% of patients. The catheter insertion audits were notable for the fact that only 1 of 6 health care workers (and 0/5 physicians) washed their hands before CVC insertion, and a large sterile drape was present only half the time. We noted appropriate site of catheter insertion and type of catheter dressing, absence of antibiotic ointment, and proper securing of CVCs.

Table 2. Characteristics of CVCs Undergoing Audit to Assess Catheter Care

	% of CVCs	
	Before Behavioral Intervention*	After Behavioral Intervention†
Insertion site		
Subclavian	53	60
Internal jugular	41	33
Femoral	6	7
Location of catheter insertion		
Surgical ICU	73	84
Operating room	21	10
Emergency department	1	2
Other (hospital ward, outside hospital)	5	4
Dressing type		
Transparent	93	98
Gauze	3	1
Both	4	1
Dressing dated	11	21
Absence of antibiotic ointment	97	96
Stopcocks present	70	24

Abbreviations: CVC, central venous catheter; ICU, intensive care unit.
*Percentages are based on 171 CVCs in 99 patients.
†Percentages are based on 138 CVCs in 72 patients.

Table 3. Behavior Patterns Associated With CVC Insertion

	No. (%) of CVCs	
	Before Intervention*	After Intervention†
Appropriate hand hygiene	1 (17)	3 (30)
Sterile gown	6 (100)	10 (100)
Mask	6 (100)	10 (100)
Sterile gloves	6 (100)	10 (100)
Large sterile drape	3 (50)	8 (80)
Absence of antibiotic ointment	6 (100)	10 (100)
Catheter sutured in	5 (83)	10 (100)
Transparent dressing appropriately placed	6 (100)	10 (100)

Abbreviation: CVC, central venous catheter.
*Percentages are based on 6 CVCs in 6 patients.
†Percentages are based on 10 CVCs in 10 patients.

EFFECT OF BEHAVIORAL INTERVENTION

After obtaining these results, a behavioral intervention was instituted aimed at nurses and physicians in July 2001. A second set of bedside audits on CVC maintenance was performed on 138 randomly selected CVCs in 72 patients from November 2001 through February 2002, 5 to 8 months after the behavioral intervention was initiated (Figure). Patient characteristics and catheter days were similar before and after the behavioral intervention (Table 1). Although 25% of patients undergoing the audit before and after the behavioral intervention were in contact isolation, this was for distant site infection or colonization, most commonly with oxacillin-resistant *Staphylococcus aureus*, vancomycin-resistant *Enterococcus faecium*, or *Clostridium difficile*. If any of these distant site infections resulted in a bacteremia, they would be categorized as a secondary BSI and would not be included in the CRBSI data. Audits were also performed on 10 randomly selected CVC insertions during the same time period. Improvements were noted on both areas where deficiencies were noted on CVC maintenance. Use of stopcocks decreased from 70% to 24% ($P<.001$), whereas properly dating the CVC dressing improved somewhat from 11% to 21% ($P<.001$; Table 2). Absolute increases in the use of maximal sterile barrier precautions (50%-80%; $P=.29$) and appropriate hand hygiene (17%-30%; $P>.99$) were also noted, although neither of these was statistically significant, possibly relating to the small number of CVC insertion audits performed (Table 3). Also notable was the impact of geographic location of catheter insertion on the anatomic site of CVC placement. Although the subclavian vein was cannulated more than 60% of the time before and after the behavioral intervention in CVCs placed in the ICU, more than 70% of CVCs inserted in the operating room before a patient's admission were placed into the internal jugular vein. Compliance with best practice remained high in principles that were appropriate before the behavioral intervention (Tables 2 and 3).

CRBSI RATES

A total of 2716 patients were surveyed during the 24 months of the study before the behavioral intervention (this represents 6 months of additional follow-up to data published by Coopersmith et al[9]). In this 2-year span after the previous educational program, a total of 32 CRBSIs occurred in 9353 catheter-days (3.4/1000 catheter-days). This compared favorably with the NNIS rate of 5.8/1000 catheter-days at the time. An additional 1773 patients were followed up in the 15 months after the behavioral intervention. Seventeen CRBSIs occurred in 6152 catheter-days during this time, a rate of 2.8/1000 catheter-days (Figure; $P=.40$ compared with before the behavioral intervention). The composite NNIS rate of surgical, trauma, and burn ICUs went up to 7.6 per 1000 catheter-days during this time, so the CRBSI rate in our surgical ICU now stands at approximately one third the national average.[36]

Most cultures yielded only a single organism, including 28 of 32 before the behavioral intervention and 15 of 17 after the behavioral intervention. The proportion of gram-positive to gram-negative bacteria was relatively similar throughout the course of the study, although there was a substantial drop in the incidence of *E faecium* after the behavioral intervention (**Table 4**).

COMMENT

This study demonstrates that a previous educational program that successfully decreased CRBSIs in our surgical ICU 3-fold[9] correlated only modestly with adherence to best-practice principles when behavior was audited 18 months later. A subsequent behavioral intervention designed to improve compliance was generally successful in areas where deficiencies were noted. A trend toward a continued decrease in CRBSI rates was also evident after the behavioral intervention, with rates falling from

3.4/1000 catheter-days to 2.8/1000 catheter-days. Although this 18% decrease was not statistically significant, it occurred at the same time that the average CRBSI rate in surgical ICUs nationally was increasing by an even higher percentage.[36]

Our results demonstrate the importance of correlating didactic teaching with appropriate clinical behavior. Similar to other studies that demonstrate that teaching health care workers can substantially limit the number of CRBSIs,[9-14] the previous educational program decreased our infection rate 3-fold.[9] An obvious conclusion was that lessons taught in the program directly translated into proper bedside care, leading to the observed result. However, this is based on the assumption that external factors played no role in its success. The results of our first set of audits cannot eliminate such confounding factors having a major impact because of the multiple areas identified where compliance with evidence-based guidelines of infection control was worse than expected.

It is likely that randomly checked bedside behavior would have been more compliant with best practice immediately after the conclusion of the previous educational program than it was when the first set of bedside audits was completed 18 months later. Worsening practice patterns could be secondary to decreased attention to the issue throughout the ICU or to continued staff turnover. Of the 69 nurses present when the previous educational program was implemented, 10 (14%) had left before the first set of bedside audits were performed 18 months later. Since all new nurses hired to the surgical ICU have been required to take the identical self-study module and pass the same test used in July 1999, it is therefore likely that an ICU-wide decrease in attention to CRBSI rather than nursing turnover was the dominant factor influencing the audit results. The fact that CRBSI rates had not risen when the initial set of behavioral audits were performed indicates that (1) the deficiencies in practice patterns were not enough to lead to nosocomial infections or (2) worsening practice patterns were recently setting in and infection rates were due to rise in the relatively near future. Although we cannot fully distinguish between these possibilities, the discrepancy between didactic teaching and clinical behavior suggests that recertification should be considered after a successful educational program. Because nosocomial infection is an ongoing problem that cannot be totally eliminated using current techniques of infection control, mandatory yearly testing on elements covered in the educational program would ensure continued attention to this important cause of morbidity and mortality in critically ill surgical patients.

Despite the 18 months between the previous educational program and the first set of bedside audits, the deviations between observed clinical practice and best practice were disappointing. Although the fact that only a few of those inserting CVCs used appropriate hand hygiene was not unexpected on the basis of the published literature, it was sobering to learn that no residents washed their hands on the first set of bedside audits. Lack of attention to hand hygiene has been a chronic problems in hospitals worldwide for decades, with physicians often having the worst compliance.[23-25,37] However, it is disturbing that surgical residents who would never consider beginning an operation without scrubbing their hands did not feel the need to wash their hands or use alcohol foam before placing a catheter expected to stay in a patient's central circulation for a number of days. Similarly, the fact that a large sterile drape was used only half of the time demonstrates a lack of understanding of how one's actions on CVC insertion have a potential impact in preventing morbidity days later. The fact that only 11% of CVC dressings were appropriately dated primarily represents a documentation failure rather than a clinical practice failure. The common occurrence of a CVC placed less than 7 days earlier with a transparent dressing in good condition but without documentation of when the dressing was placed would be charted as not having an adequately dated dressing (since no documentation was present), although the dressing was not expired. However, the importance of a complete medical record cannot be overemphasized, and even if the dressing was sterile and not expired, this lack of documentation is not optimal medical practice.

Table 4. Microbiological Features of All CRBSIs Identified Before and After Behavioral Intervention for 39 Months

	No. (%) of CRBSIs	
	Before Behavioral Intervention*	After Behavioral Intervention†
Gram-positive bacteria	**28** (76)	**12** (63)
Enterococcus faecium	10 (27)	1 (5)
Coagulase-negative *Staphylococcus*	9 (24)	6 (32)
Enterococcus faecalis	5 (14)	4 (21)
Staphylococcus aureus	3 (8)	1 (5)
Streptococcus pneumoniae	1 (3)	0
Gram-negative bacteria	**9** (24)	**6** (32)
Acinetobacter baumanii	3 (8)	1 (5)
Klebsiella pneumoniae	2 (5)	0
Pseudomonas aeruginosa	1 (3)	2 (11)
Enterobacter cloacae	1 (3)	2 (11)
Stenotrophomonas maltophilia	1 (3)	0
Klebsiella oxytoca	1 (3)	0
Proteus mirabilis	0	1 (5)
Yeast	**0**	**1** (5)
Candida albicans	0	1 (5)

Abbreviation: CRBSI, catheter-related bloodstream infection.
*Percentages are based on 37 culture isolates from 32 patients.
†Percentages are based on 19 culture isolates from 17 patients.

Despite the improvements seen after the behavioral intervention, no statistically significant decrease accompanied the continued downward trend in our infection rates. In large part, we believe this is due to our previous success. It was easy to show improvement when our infection rates were double the national average, but much more difficult to show further improvement when our rates were one half to one third the national average. It is possible that we have reached the lower limit of success in CRBSI rates that can be reached with education alone. However, it is possible that the lack of a greater impact on CRBSI rates might have been due to the diffuseness of the message in the behavioral intervention. It is unclear whether further incremental improvement in specific behaviors such as hand hygiene would decrease infection rates further.

This study has a number of limitations. We are unable to specifically identify the factors responsible for the success of our previous educational program. Although we believe the fact that modest compliance with best practice across a variety of behaviors accounts for at least a portion of our previously reported 3-fold decrease in CRBSI rates, we cannot identify which factors were more important than others (although deficiencies in dating of dressings, use of stopcocks, hand hygiene, and maximal sterile barrier precautions make these particular facets unlikely to have played a role in the success of the program). In addition, the very small number of insertion observations (n=16) severely limits their usefulness. Since we believed that knowledge of the observation alone could easily lead to altered behaviors (such as paying closer to attention to sterility than usual), this limited the number of audits, and in turn, makes all conclusions resulting from them questionable. It is also possible that although audits were intended to be random for 7 months, investigator bias was inadvertently introduced since the 3 team members performing observations were on the task force that designed the audit tool and the subsequent behavioral intervention.

Despite these limitations, this study advances our understanding of the relationship between education, behavior, and the prevention of CRBSIs. Our previous educational program led to modestly appropriate bedside behaviors, although nurses and physicians were not as compliant as might have been predicted on the basis of the sustained decrease in infections seen after its implementation. The behavioral intervention described herein led to improvements in bedside practice and was associated with a nonstatistically significant trend toward lower infection rates. Although continued use of education initiatives is a simple way to sustainably keep nosocomial bacteremias low, behavioral outcomes need to be monitored in addition to infection rates for these programs to have optimal utility.

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