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A multicenter intervention to prevent catheter-associate bloodstream infections

David K. Warren

Washington University School of Medicine in St. Louis

Sara E. Cosgrove

Johns Hopkins School of Hygiene and Public Health

Daniel J. Diekema

University of Iowa College of Medicine

Gianna Zuccotti

Memorial Sloan-Kettering Cancer Center

Michael W. Climo

Hunter Holmes McGuire Veterans Affairs Medical Center

See next page for additional authors

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Authors

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Author(s): David K. Warren , MD, MPH, Sara E. Cosgrove , MD, Daniel J. Diekema , MD, Gianna Zuccotti , MD, Michael W. Climo , MD, Maureen K. Bolon , MD, Jerome I. Tokars , MD, MPH, Gary A. Noskin , MD, Edward S. Wong , MD, Kent A. Sepkowitz , MD, Loreen A. Herwaldt , MD, Trish M. Perl , MD, MSc, Steven L. Solomon , MD, Victoria J. Fraser , MD

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ORIGINAL ARTICLE

A Multicenter Intervention to Prevent Catheter-Associated Bloodstream Infections

David K. Warren, MD, MPH; Sara E. Cosgrove, MD; Daniel J. Diekema, MD; Gianna Zuccotti, MD; Michael W. Climo, MD; Maureen K. Bolon, MD; Jerome I. Tokars, MD, MPH; Gary A. Noskin, MD; Edward S. Wong, MD; Kent A. Sepkowitz, MD; Loreen A. Herwaldt, MD; Trish M. Perl, MD, MSc; Steven L. Solomon, MD; Victoria J. Fraser, MD; for the Prevention Epicenter Program

BACKGROUND. Education-based interventions can reduce the incidence of catheter-associated bloodstream infection. The generalizability of findings from single-center studies is limited.

OBJECTIVE. To assess the effect of a multicenter intervention to prevent catheter-associated bloodstream infections.

DESIGN. An observational study with a planned intervention.

SETTING. Twelve intensive care units and 1 bone marrow transplantation unit at 6 academic medical centers.

PATIENTS. Patients admitted during the study period.

INTERVENTION. Updates of written policies, distribution of a 9-page self-study module with accompanying pretest and posttest, didactic lectures, and incorporation into practice of evidence-based guidelines regarding central venous catheter (CVC) insertion and care.

MEASUREMENTS. Standard data collection tools and definitions were used to measure the process of care (ie, the proportion of non-tunneled catheters inserted into the femoral vein and the condition of the CVC insertion site dressing for both tunneled and nontunneled catheters) and the incidence of catheter-associated bloodstream infection.

RESULTS. Between the preintervention period and the postintervention period, the percentage of CVCs inserted into the femoral vein decreased from 12.9% to 9.4% (relative ratio, 0.73; 95% confidence interval [CI], 0.61-0.88); the total proportion of catheter insertion site dressings properly dated increased from 26.6% to 34.4% (relative ratio, 1.29; 95% CI, 1.17-1.42), and the overall rate of catheter-associated bloodstream infections decreased from 11.2 to 8.9 infections per 1,000 catheter-days (relative rate, 0.79; 95% CI, 0.67-0.93). The effect of the intervention varied among individual units.

CONCLUSIONS. An education-based intervention that uses evidence-based practices can be successfully implemented in a diverse group of medical and surgical units and reduce catheter-associated bloodstream infection rates.

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Central venous catheters (CVCs) are indispensable in the care of critically ill patients. However, their use is not without risk. Catheter-associated bloodstream infections (CA-BSIs) are common healthcare-associated infections in intensive care unit (ICU) patients¹ and have been estimated to occur in 3%-7% of all patients with CVCs.² Nontunneled CVCs are the most frequently used devices in ICUs. Despite being used for relatively brief periods, these catheters are associated with a higher rate of infection than are tunneled catheters or totally implanted ports, which are used for relatively longer periods.³

Use of newer devices such as antimicrobial- and antiseptic-impregnated CVCs reduces the risk of CA-BSI⁴⁻⁷; however, use of these devices may not be more effective than ensuring use of appropriate methods for insertion, use, and care of CVCs. Practices that reduce the risk of CA-BSIs include the following: (1) use of maximal barrier precautions during CVC insertion (ie, a surgical mask, sterile gown, sterile gloves, and large sterile drapes),^{8,9} (2) placement of the catheter in the subclavian vein rather than the internal jugular or femoral vein,^{10,11} (3) changing catheters only when necessary,^{12,13} and

From the Department of Medicine, Washington University School of Medicine, Saint Louis, Missouri (D.K.W., V.J.F.); the Department of Public Health and Hygiene, Johns Hopkins School of Hygiene and Public Health, Baltimore, Maryland (S.E.G., T.M.P.); the Department of Internal Medicine, University of Iowa College of Medicine, Iowa City, Iowa (D.J.D., L.A.H.); the Department of Medicine (G.Z.) and the Department of Internal Medicine (K.A.S.), Memorial Sloan-Kettering Cancer Center, New York, New York; the Department of Internal Medicine, Hunter Holmes McGuire Veterans Affairs Medical Center, Richmond, Virginia (M.W.C., E.S.W.); the Department of Internal Medicine, Northwestern University, Feinberg School of Medicine, Chicago, Illinois (M.K.B., G.A.N.); and the Division of Healthcare Quality Promotion, Centers for Disease Control and Prevention, Atlanta, Georgia (J.I.T., S.L.S.).

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(4) changing dressings on CVC exit sites when they become nonocclusive, soiled, or bloody.¹⁴ These practices have been incorporated into national guidelines.^{15,16} Currently, the Healthcare Infection Control Practices Advisory Committee (HICPAC) of the Centers for Disease Control and Prevention (CDC) recommends that hospitals implement comprehensive educational programs that teach proper CVC insertion and maintenance techniques.

Several studies have examined education-based interventions to reduce the incidence of CA-BSIs in single institutions¹⁷⁻²² and within a single city.²³ These interventions have used didactic training sessions^{17,21,23} or a combination of both didactic and hands-on training.^{20,19} The interventions have educated various groups of healthcare workers, including resident physicians and medical students,²⁰ physicians-in-training and nursing staff,^{17,19,21} intensivists and nurses,²² and nurses alone.²³ Six of these studies reported a 28%-72% decrease in the incidence of CA-BSI in the postintervention period.¹⁸⁻²²

These studies demonstrate that education-based interventions can help prevent CA-BSIs. However, questions remain regarding the generalizability of these interventions to multiple healthcare systems, because the studies were conducted either at single centers or within a single city. Thus, an effective intervention that could be implemented broadly would have a clear public health benefit. The purpose of this study was to implement a multifaceted, education-based intervention in ICUs at 6 academic medical centers and to assess the effect of the intervention on processes of CVC care and the incidence of bloodstream infection associated with nontunneled catheters.

METHODS

Study Sites

The intervention took place in 13 ICUs at 6 academic tertiary care hospitals (mean size, 775 beds; range, 427-1,385 beds) participating in the CDC Prevention Epicenter Program. Adult ICUs and select bone marrow transplantation units were eligible for study; 2 or 3 units participated at each hospital. Units were selected by local investigators if they met the following criteria: (1) the incidence of CA-BSI had been at or above the mean unit-specific rate reported in the National Nosocomial Infection Surveillance System for at least 12 months, (2) the incidence of CVC utilization was stable, and (3) the unit leadership (ie, the unit medical and nursing directors) were willing to participate in the study. For purposes of the study, units were defined as being primarily medical (ie, medical ICU, coronary care unit, or bone marrow transplantation unit), surgical (ie, surgical ICU or cardiothoracic ICU), or mixed (ie, medical-surgical ICU or neurology-neurosurgical ICU).

Description of the Intervention

The intervention consisted of several elements that were implemented over a 3-month period in each unit. The first

element consisted of reviewing and updating hospital and/or unit policies and procedures concerning the insertion, care, and use of nontunneled CVCs. Local investigators used a standardized data collection tool to survey existing policies and procedures in each unit and compared these policies with the CDC/HICPAC recommendations.¹⁶ For those units that either did not have a defined policy or had a policy not consistent with current CDC guidelines, the individual investigator worked with the appropriate local staff to create or update the policy.

The second element of the intervention consisted of educating staff. This was accomplished by 3 methods. Didactic lectures were given for physicians and nursing staff; investigators used a standardized slide show for these presentations. A standardized, 9-page, self-study module with accompanying 24-question pretest and posttest (which were identical) was distributed to physicians who inserted nontunneled catheters and to nursing staff in each unit. The self-study module, based on a previously studied module,²² provided information on risk factors for CA-BSIs, and proper practices for the insertion, care, and use of CVCs were updated to reflect CDC/HICPAC recommendations published in 2002. Fact sheets and posters highlighting proper techniques for CVC insertion and care were placed in the units in places that staff were likely to see and read them. The primary messages of the intervention material were as follows: (1) the subclavian vein is the preferred insertion site for a nontunneled CVC, and the femoral vein is the least desirable site; (2) catheters should be inserted using maximal sterile barrier precautions; (3) catheter insertion site dressings should be kept clean, dry, and intact; and (4) catheter dressings should be properly dated, to ensure regular dressing changes.

Any other new interventions that were performed at individual Prevention Epicenter Program sites and that might affect the outcome of this study (ie, bundling of supplies and/or procedure carts or hands-on training of staff) were monitored by individual investigators at their sites and recorded. Of note, one ICU instituted an education-based intervention at the start of the preintervention period.²⁴ The overall catheter-associated infection rate was calculated both with and without this unit's data.

Collection of Data

Baseline data collection to identify ICU-acquired, catheter-related bloodstream infections was initiated in January 2002, which was 5-7 months before the intervention was begun, and it was continued for 15-18 months after the intervention in each study unit (ie, until December 2003). Study personnel collected data on the total number of patient-days and the total number of nontunneled catheter-days per month per ICU. To determine whether the intervention changed the processes of CVC insertion and care within the study units, once per week (Monday through Friday), study personnel conducted unannounced point-prevalence surveys of CVCs pres-

TABLE 1. Components of the Bloodstream Infection Prevention Intervention Implemented by the Various Study Units

Unit	Unit type	Updated CVC insertion and/or care policies	Posters	Fact sheets	CVC lecture	Bundling CVC insertion supplies	Hands-on training	Intervention supported by unit staff, Likert scale ^a
A	Medical	Yes	Yes	Yes	Yes	Yes	No	2.0
B	Surgical	Yes	Yes	Yes	No	Yes	No	4.2
C	Medical	Yes	Yes	Yes	Yes	No	No	3.6
D	Medical	Yes	Yes	Yes	Yes	No	No	3.8
E	Medical	Yes	Yes	Yes	Yes	Yes	Yes	4.2
F	Mixed	Yes	Yes	Yes	Yes	No	No	4.0
G	Mixed	Yes	Yes	No	Yes	Yes	No	3.8
H	Surgical	Yes	Yes	Yes	Yes	No	No	4.0
I	Surgical	Yes	Yes	No	Yes	Yes	No	3.7
J	Surgical	Yes	Yes	Yes	Yes	Yes	No	3.6
K	Medical	Yes	Yes	Yes	No	Yes	No	4.6
L	Surgical	Yes	Yes	Yes	No	No	No	3.8
M	Surgical	Yes	Yes	Yes	Yes	Yes	No	3.6

NOTE. CVC, central venous catheter.

^a Scale: 1 indicates "strongly disagree" and 5 indicates "strongly agree" with statement.

ent in patients in the unit at that time. The anatomic location of nontunneled catheters (ie, in the femoral, subclavian, or internal jugular veins) and the condition of catheter insertion site dressings for both tunneled and nontunneled catheters (ie, whether the dressing was visibly bloody and whether the dressing was dated) were noted on a standard data collection tool. For the 5 units that used antimicrobial- or antiseptic-coated catheters, the number of these catheters used during the study period was noted. Data on the anatomical sites of CVCs were collected through March 2003 for all study units. We reviewed all blood cultures that yielded a pathogen for which the blood samples were obtained in the study units or within 48 hours after discharge from the unit. A bloodstream infection was considered to be unit-related if it occurred 48 hours after admission to or 48 hours after discharge from the study unit. CA-BSI was defined according to published criteria,²⁵ with one exception: because the intervention was focused on the insertion and care of nontunneled CVCs, patients with totally implantable ports or hemodialysis catheters only were excluded from the analysis their catheter-days were not added to the monthly denominator data, since these types of catheters have infection risks and care processes that are distinct from other central venous access devices.

To assess the extent to which the intervention was implemented in each unit, study personnel collected data on the total number of eligible unit nurses and physicians who received the self-study module during the intervention period and whether the various components of the intervention (e.g., posters and didactic sessions) were used in each unit. At the end of the intervention period, before the outcome data were analyzed, investigators at each hospital filled out a questionnaire to rate the degree of support for the intervention given

by the unit's medical director, nursing director, nursing staff, and physician staff. The answers to the questions were presented as a Likert scale (ie, 1 = strongly disagree; 5 = strongly agree).

Analysis of Data

Data were analyzed using SPSS for Windows, version 11.0 (SPSS). The incidence rate of CA-BSIs per 1,000 catheter-days was calculated, and a relative rate of CA-BSIs in the postintervention period (including the 0-3-month intervention period) compared with the preintervention period was determined, with 95% confidence intervals (CIs), for each unit individually and in aggregate.²⁶ The relative ratio of having a femoral catheter and a bloody or undated dressing during the preintervention and the postintervention periods was calculated for each unit and in aggregate; the χ^2 test was used to compare the proportions. A 2-tailed *P* value of less than .05 was considered statistically significant.

Approvals and Informed Consent

The institutional review boards at each study site and at the CDC approved this study. The review boards concurred that written consent was not required from each patient in the study units, because the measures used were considered standard-of-care. One review board required that the investigators mail the self-study modules and the pretest and posttest to the nurses and residents, because they felt that staff could be intimidated into participating by supervisors or investigators if the tests were done in a group. The CDC, which sponsored the study, was involved in the study design and in the writing of the report for publication.

TABLE 2. Changes in Observed Markers of Central Venous Catheter (CVC) Insertion and Care During Study Periods, by Hospital Unit

Unit	Unit type	Femoral vein insertion site ^a			Blood at dressing site			Dated dressing		
		Preintervention period, proportion (%) of CVCs	Postintervention period, ^b proportion (%) of CVCs	Relative ratio (95% CI)	Preintervention period, proportion (%) of CVCs	Postintervention period, ^b proportion (%) of CVCs	Relative ratio (95% CI)	Preintervention period, proportion (%) of dressings	Postintervention period, ^b proportion (%) of dressings	Relative ratio (95% CI)
A	Medical	45/120 (37.5)	35/183 (19.1)	0.51 (0.35-0.74) ^c	26/117 (22.2)	21/175 (12)	0.54 (0.32-0.91) ^c	35/117 (29.9)	45/175 (25.7)	0.86 (0.59-1.25)
B	Surgical	4/50 (8.0)	4/291 (1.4)	0.17 (0.04-0.66) ^c	22/50 (44.0)	93/298 (31.2)	0.71 (0.50-1.01)	11/50 (22.0)	100/298 (33.6)	1.53 (0.88-2.63)
C	Medical	23/93 (24.7)	21/89 (23.6)	0.95 (0.57-1.60)	13/108 (12.0)	11/126 (8.7)	0.73 (0.34-1.55)	5/108 (4.6)	29/126 (23.0)	4.97 (1.99-12.4) ^c
D	Medical	16/58 (27.6)	15/63 (23.8)	0.86 (0.47-1.58)	11/63 (17.5)	8/84 (9.5)	0.55 (0.23-1.28)	0/63 (0)	14/84 (16.7)	Undefined
E	Medical	17/204 (8.3)	35/294 (11.9)	1.43 (0.82-2.48)	100/206 (48.5)	102/286 (35.7)	0.73 (0.60-0.91) ^c	118/206 (57.3)	162/286 (56.6)	0.99 (0.85-1.16)
F	Mixed	2/47 (4.3)	2/133 (1.5)	0.35 (0.05-2.44)	12/49 (24.5)	44/142 (31.0)	1.27 (0.73-2.19)	17/49 (34.7)	59/142 (41.5)	1.20 (0.78-1.84)
G	Mixed	38/103 (36.9)	31/181 (17.1)	0.46 (0.31-0.70) ^c	6/133 (4.5)	4/230 (1.7)	0.39 (0.11-1.34)	133/133 (100)	230/230 (100)	Undefined
H	Surgical	3/40 (7.5)	3/116 (2.6)	0.34 (0.07-1.64)	13/50 (26.0)	43/134 (32.1)	1.23 (0.73-2.09)	21/50 (42.0)	53/134 (39.6)	0.94 (0.64-1.39)
I	Surgical	0/43 (0)	3/140 (2.1)	Undefined	7/236 (3.0)	23/488 (4.7)	1.59 (0.69-3.65)	0/236 (0)	0/488 (0)	Undefined
J	Surgical	1/95 (1.1)	8/190 (4.2)	4.00 (0.51-31.52)	19/94 (20.2)	47/194 (24.2)	1.20 (0.75-1.92)	13/94 (13.8)	23/194 (11.9)	0.86 (0.45-1.62)
K	Medical	13/57 (22.8)	76/421 (18.1)	0.79 (0.47-1.33)	15/60 (25.0)	100/432 (23.1)	0.93 (0.58-1.48)	25/60 (41.7)	268/432 (62.0)	1.49 (1.09-2.03) ^c
L	Surgical	16/281 (5.7)	9/246 (3.7)	0.64 (0.29-1.43)	32/273 (11.7)	28/238 (11.8)	1.00 (0.62-1.62)	9/273 (3.3)	59/238 (27.8)	7.52 (3.81-14.8) ^c
M	Surgical	0/191 (0)	14/363 (3.9)	Undefined	125/192 (65.1)	183/363 (50.4)	0.77 (0.67-0.90) ^c	46/192 (24.0)	52/363 (14.3)	0.60 (0.42-0.85) ^c
All units	...	178/1382 (12.9)	256/2710 (9.4)	0.73 (0.61-0.88) ^c	401/1631 (24.6)	707/3190 (22.2)	0.90 (0.81-1.00)	434/1631 (26.6)	1094/3190 (34.3)	1.29 (1.17-1.42) ^c

NOTE. CI, confidence interval.

^a For nontunneled CVCs only.

^b Postintervention data for this table are from the period through March 2003 only (see Methods).

^c Statistically significant.

TABLE 3. Number and Rate of Catheter-Associated Bloodstream Infections (CA-BSIs) During the Study Periods, by Hospital Unit

Unit	Unit type	No. of CA-BSIs (no. per 1,000 CVC-days)		Relative rate (95% CI)
		Preintervention period (20,381 CVC-days)	Postintervention period (57,347 CVC-days)	
A	Medical	24 (21.4)	31 (9.7)	0.45 (0.26-0.81) ^a
B	Medical	32 (19.2)	42 (9.7)	0.50 (0.31-0.83) ^a
C	Medical	11 (12.6)	28 (10.8)	0.86 (0.41-1.90)
D	Medical	8 (15.3)	12 (6.3)	0.41 (0.16-1.17)
E	Medical	21 (16.0)	86 (18.5)	1.16 (0.71-1.96)
F	Mixed	16 (13.0)	23 (5.5)	0.42 (0.21-0.86) ^a
G	Mixed	20 (11.4)	31 (7.8)	0.69 (0.38-1.28)
H	Surgical	13 (9.7)	36 (8.1)	0.83 (0.43-1.71)
I	Surgical	26 (6.4)	65 (7.2)	1.13 (0.71-1.85)
J	Surgical	5 (5.5)	37 (11.5)	2.10 (0.82-6.86)
K	Surgical	28 (12.8)	70 (12.0)	0.93 (0.59-1.50)
L	Surgical	13 (6.1)	21 (4.1)	0.68 (0.32-1.47)
M	Surgical	12 (9.5)	26 (5.3)	0.56 (0.27-1.21)
All units	...	229 (11.2)	508 (8.9)	0.79 (0.67-0.93) ^a

NOTE. CI, confidence interval; CVC, central venous catheter.

^a Statistically significant

RESULTS

Baseline Characteristics of Study Units

The 13 study units had a mean of 16.7 beds (range, 12-31 beds). Their types were as follows: 4 (30.8%) were medical ICUs, 3 (23.1%) were surgical ICUs, 1 (7.7%) was a coronary care ICU, 2 (15.4%) were cardiothoracic surgical ICUs, 1 (7.7%) was a neurological-neurosurgical ICU, 1 (7.7%) was a medical-surgical ICU, and 1 (7.7%) was a bone marrow-stem cell transplantation unit. We evaluated a total of 77,728 catheter-days (20,381 in the preintervention period and 57,347 in the postintervention period) during 118,753 patient-days (30,191 in the preintervention period and 88,562 in the postintervention period). The overall proportion of CVC-days to patient-days was slightly higher in the preintervention period than in the postintervention period (0.68 vs. 0.65 catheter-days per patient-day; $P < .001$).

Implementation of the Intervention Within Individual Study Units

The implementation of key components of the intervention is noted in Table 1. Eight (62%) of 13 units bundled supplies for maximal sterile barrier precautions with catheter insertion kits, and 1 unit conducted hands-on training to teach house staff how to insert catheters using teaching mannequins. A total of 414 (75%) of 549 eligible nurses (range, 35%-100% per unit) and 276 (67%) of 410 eligible physicians (range, 17%-86% per unit) received the module. When asked whether the unit staff supported the intervention, local investigators gave answers that varied considerably by unit (mean Likert scale rating, 3.7; range, 2.0-4.6) and by staff

type (mean rating: nurse managers, 4.1; medical directors, 3.7; nursing staff, 3.8; resident physicians, 3.7; and attending physicians, 3.4).

Effect of the Intervention on CVC Care and CA-BSI Rates

During the study period, 4,821 CVC insertion sites were observed (729 tunneled and 4,092 nontunneled catheter sites). Of the 4,092 nontunneled catheters, 434 (10.6%) were inserted in the femoral vein. The total proportion of nontunneled CVCs inserted into the femoral vein decreased from 12.9% before the intervention to 9.4% after the intervention (relative ratio, 0.73; 95% CI, 0.61-0.88) (Table 2). Of the 4821 observed nontunneled and tunneled CVCs, 1108 (23%) had visible blood either on or under the insertion site dressing. The total proportion of CVCs with visible blood at the insertion site did not change significantly from the preintervention period to the postintervention period (relative ratio, 0.90; 95% CI, 0.81-1.00) (Table 2). Finally, for 1528 (31.7%) of CVC dressings, the date that they were last changed was recorded. The total proportion of dated dressings increased from 26.6% before the intervention to 34.4% after the intervention (relative ratio, 1.29; 95% CI, 1.17-1.42) (Table 2).

During the study, 737 CA-BSIs occurred. Three units (units A, B, and F) had significant decreases in CA-BSI rates after the intervention. The overall rate of CA-BSI significantly decreased from the preintervention period to the postintervention period (11.2 vs. 8.9 cases per 1,000 CVC-days; rate ratio, 0.79; 95% CI, 0.67-0.93) (Table 3). Exclusion of data from the unit that had an earlier intervention separate from the study intervention resulted in a slight reduction in the overall postintervention infection rate (rate ratio, 0.73; 95% CI, 0.62-

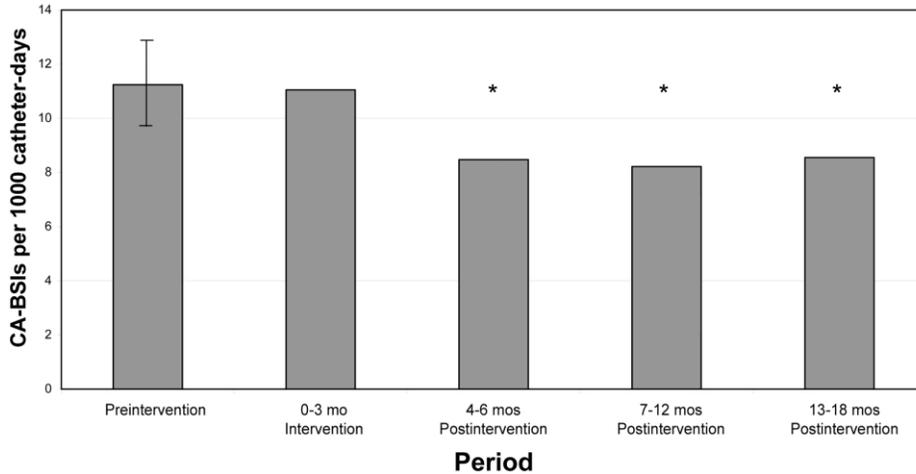


FIGURE 1. Overall incidence of catheter-associated bloodstream infection (CA-BSI) during the preintervention period and postintervention periods for 13 units at 6 hospitals. Whiskers, 95% confidence interval estimate. * $P < .05$ versus the preintervention period.

0.87). The overall CA-BSI rate was lowest in the period 7-12 months after the start of the intervention (Figure 1).

The change in the observed proportion of CVCs that were placed in the femoral vein correlated most closely with the overall change in the CA-BSI rate ($r = 0.93$; $r^2 = 0.86$; $P < .001$, by 2-tailed Pearson correlation) (Figure 2). The change in the CA-BSI rate was not correlated with changes in the proportion of dated insertion site dressings or visibly bloody dressings, with the proportion of nurses or physicians who completed the self-study module, or with investigator-perceived degree of support for the intervention among unit personnel (data not shown).

DISCUSSION

CA-BSIs are preventable; however, many of the prevention methods described in the literature rely on technological advance, rather than ensuring that proper techniques are used. The multifaceted, education-based intervention we describe, implemented in 13 units at 6 hospitals, decreased the overall incidence of CA-BSIs by 21%. The decrease in the infection rate persisted throughout the 18-month postintervention period. The intervention resulted in changes in CVC insertion practices in the study units; from the preintervention to the postintervention period, there was a 27% reduction in the prevalence of nontunneled CVCs inserted in the femoral vein and a 29% increase in the proportion of catheter dressing sites that had that date of last dressing change clearly marked. Among individual units, the intervention had variable effects. The efficacy of the intervention correlated most closely with changes in the insertion sites for nontunneled CVCs.

To our knowledge, this is the first multiple-center, education-based intervention to prevent CA-BSI among patients at acute care facilities. The reduction in CA-BSI rates in our study reached a maximum approximately 7-12 months after

the start of the intervention. The delay might have been a function of the time required to change nurses' and physicians' actual practices, rather than the time required to change the policies. The change in CVC insertion and care practice that best correlated with a reduction in the infection rate was the degree to which an individual unit reduced the proportion of nontunneled catheters inserted in the femoral vein. Pre-

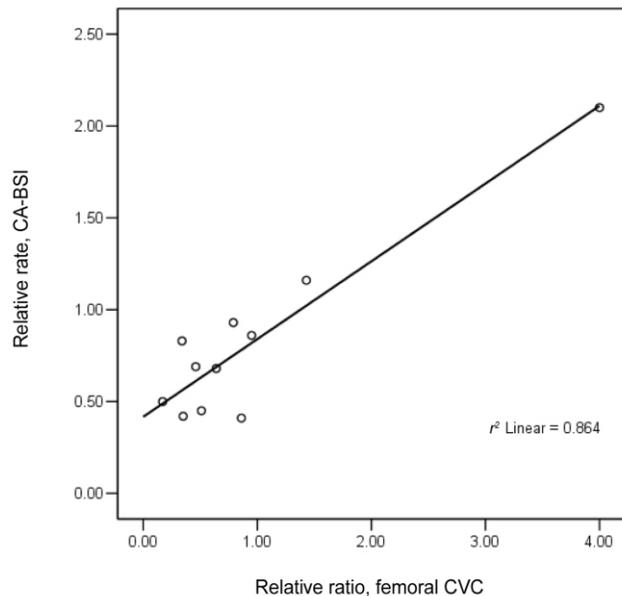


FIGURE 2. Correlation of the relative ratio for use of femoral vein central venous catheter (CVC) insertion site and the relative rate of catheter-associated bloodstream infection (CA-BSI) before and after the intervention. Data for units with undefined relative ratios for use of the femoral catheter insertion site (units I and M) are not shown.

vious studies have noted that CVCs inserted in the femoral vein are associated with a higher risk of subsequent CA-BSIs and venous thrombosis than are CVCs placed in the subclavian vein or internal jugular vein.^{10,11,27} However, because of the multifaceted nature of this study, it cannot be concluded that this single change in practice reduced infection rates. It is possible that changes in this insertion practice may have been a surrogate for other improvements in catheter insertion practices (eg, use of maximal sterile barrier precautions) and/or for the level of support for the intervention by physician leadership in each unit.

Although insertion site dressing care did improve, as measured by the proportion of dressings properly dated, the overall rate of dating remained low (34%). In one unit (unit I), no dressing sites were dated before or after the intervention. This unit had a policy of routine daily gauze dressing changes before the start of the intervention and did not change this policy. The proportion of visibly bloody dressings significantly decreased in 3 individual units but not overall. The percentage of visibly bloody dressings at baseline in this study was highly variable (3%–65%), which might have been more a function of the patient populations in the individual units (eg, cardiac patients receiving anticoagulants) than a function of nursing care. Previous studies have shown that the local opinion leaders can affect the success or failure of behavior-based interventions.^{28,29} However, we did not find a correlation between the investigators' perception of how strongly the medical and nursing staff supported the intervention and the postintervention infection rate. We do not know whether the level of support from the leadership truly did not affect the outcome of the study or whether the method we used to assess leaders' support was too imprecise.

Although there was an overall decrease in CA-BSI rates, there was variability in the impact of the intervention among the various units. Three units (units E, I, and J) had non-significant increases in the rate of infection. All 3 of these units had increases in the proportion of CVCs placed in the femoral vein, 2 had an increase or no change in the proportion of visibly bloody dressings, and all 3 had no change in the proportion of dated dressings from the preintervention period to the postintervention period. There are several possible explanations for these observations. Despite a relatively high level of perceived support by investigators in one unit (unit E), it may have been possible that the intervention was not accepted and implemented as completely in these units. Because resources were limited, some processes of care were not measured, such as use of maximal sterile barrier precautions during catheter insertion and use of sterile technique during dressing changes, which might have correlated more closely with changes in infection rates. The variability in the effect of this intervention among the 13 units in this study highlights the complexity of implementing education-based interventions at multiple centers.

The use of a preintervention-postintervention design is a potential limitation of this study. Unmeasured changes in

patient and unit characteristics could have occurred during the study that might account for the decrease in CA-BSI rates. Although we cannot completely exclude the possibility that unanticipated changes occurred in the study units, local investigators consulted with unit and infection control staff to assess other obvious confounders, such as the earlier intervention performed in one of the study units. No other interventions or significant changes were identified. In addition, no units introduced the use of antimicrobial-impregnated catheters, other than the 5 units that were already using them at the start of the study. Moreover, to ensure that staff members at each site accepted the intervention, we allowed investigators at each site to vary the intervention somewhat to fit the needs of their site. Thus, although changes in choice of catheter insertion site correlated best with changes in the infection rate, we cannot determine from our results whether the decrease in the infection rate was the result of all the changes in aggregate or whether a single aspect of the intervention was the critical component.

The overall effect of this intervention in reducing CA-BSI rates in these units was substantial. On the basis of data in the literature, we estimated that because approximately 131 infections were prevented among the 13 study units in the postintervention period, 13 deaths attributable to CA-BSI were averted,³⁰ 260–286 days of hospitalization were avoided,³¹ and \$3,111,381 to \$4,358,108 in excess hospital costs were saved.^{32,33} This study demonstrates that an education-based intervention can be successfully implemented in a diverse set of medical and surgical units and can reduce CA-BSI rates over a prolonged period.

Address reprint requests to David K. Warren, MD, MPH, Washington University School of Medicine, Campus Box 8051, 660 S. Euclid Avenue, Saint Louis, MO 63110 (dwarren@im.wustl.edu).

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