Impact of Peripherally Inserted Central Catheters on Catheter-Related Bloodstream Infections in the Intensive Care Unit

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Objectives: To determine whether using peripherally inserted central catheters (PICCs) in intensive care decreases catheter-related bloodstream infections (CRBSIs).

Methods: We performed a retrospective review of a central-line database before and after the introduction of hemodynamic monitoring with PICCs in a closed, medical-surgical, 20-bed intensive care unit and a 10-bed intermediate care unit of a tertiary-care academic medical institution. CRBSI rates were compared for a 12-month control period and a 36-month intervention period with open-ended PICCs.

Results: Two thousand four hundred seventy-four central vascular catheters were inserted in 1788 critically ill patients (21,919 catheter-days). During the control period, centrally inserted central catheter (CICC) median dwell time was 6.4 days, with a CICC CRBSI rate of 2.3 per 1000 catheter-days and a total CRBSI rate of 1.6. During the third intervention year, CICC median dwell time was 3.2 days (50% reduction; $P < 0.001$), CICC-related CRBSIs were eliminated, and the total CRBSI rate was 0.3 per 1000 catheter-days (81% reduction; $P < 0.001$).

Conclusions: Using open-ended PICCs in intensive care may be associated with shorter CICC dwell times, reduced CRBSIs, and reduced antibiotic usage. Further studies are necessary to evaluate early PICC utilization as part of future central-line infection prevention initiatives, especially considering their use may save more than 6000 lives and US $1.1 billion annually.

Key Words: bacteremia, bacterial infections, catheterization, central venous, sepsis

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The use of central venous catheters (CVCs) is critical to the management of patients in intensive care units (ICUs). More than 14 million centrally inserted central catheters (CICCs) and 3.3 million peripherally inserted central catheters (PICCs)[1] are used worldwide annually for hemodynamic monitoring, volume resuscitation, phlebotomy, hemodialysis, or medication infusion. Despite these obvious functionalities, CICCs are associated with a 3% to 5% risk of catheter-related bacteremia, extending hospital length of stay (LOS) (up to 22 days), increasing costs (US $16,000 to $56,000 per episode),[2,3] and resulting in increased mortality of 4% to 20%.[4] Despite advances in catheter technology,[5] national catheter-related bloodstream infection (CRBSI) rates remain high, averaging 3.2 to 5 per 1000 catheter-days in medical and surgical ICUs.[6] The risk of these CRBSIs are greatly increased with CICC use for more than 5 to 7 days.[7]

Complication rates for PICCs are lower than for CICCs. This difference can be attributed to the lower density of skin colonization on the arm compared with that of the torso[8] and the use of dedicated line insertion and maintenance teams. In acute-care settings, reported PICC CRBSI rates are 72% lower than non–antiseptic-impregnated CICCs (nationally 0.8 per 1000 catheter-days versus 2.9 per 1000 catheter-days).[8,9] PICCs can also be inserted at bedside in superficial veins of the upper extremities by physicians, respiratory therapists, or nurses[10,11] without risk of pneumothorax, major hemorrhage, neck hematoma, or carotid puncture.[12] Open-ended PICCs function similarly to CICCs, including central venous pressure monitoring, except that most cannot deliver fluid at rates of more than 3000 mL/h.[13,14]

In our closed tertiary-care, medical-surgical, transplant ICU, hemodynamic monitoring was adopted as an indication for PICC placement after review by the critical care practice committee. To assess its impact on CRBSIs, we performed a "before and after" retrospective review of a central-line database from 1 year before (control period) to 3 years after (intervention period) the introduction of PICCs for hemodynamic monitoring.

PATIENTS AND METHODS

Study Population

We reviewed medical records of all patients who required CVC placement in a multidisciplinary, closed, 20-bed ICU (medical-surgical, transplant, and coronary care) and in a 10-bed intermediate care unit at a 208-bed tertiary-care teaching hospital between January 1, 2000, and December 31, 2003. The institutional review board approved this study.

Definitions

We adopted the definitions of catheter infection and CRBSI proposed by the Centers for Disease Control and

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Prevention and used in the National Nosocomial Infection Surveillance System.[15,16] Catheter colonization was defined as 15 or more colony-forming units per catheter segment by semiquantitative roll-plate method. CRBSI was defined as isolation of the same organism (defined by species and antimicrobial susceptibility pattern) from the colonized catheter (>15 colony-forming units) and one or more peripheral blood cultures within 48 hours in a patient with no alternative source of bacteremia. Indications for removal and culturing of catheter and peripheral blood included insertion site erythema or purulent exudates in patients with clinical sepsis or clinical suspicion of catheter-related sepsis.

Comprehensive Central-Line Infection Prevention Strategy

All CVCs were inserted with assistance of critical care therapists. In 1999, the Department of Critical Care, in conjunction with the Department of Non-Invasive Diagnostics, deployed its first team of respiratory therapists with cognitive and field training in hemodynamic monitoring and invasive procedures such as vascular access. The team of 5 critical care therapists participated in all central-line insertions, facilitating the standardized use of a line insertion cart, full barrier precautions (mask, hat, and sterile gown and gloves with full draping), cutaneous antisepsis with povidone-iodine solution, daily assessment of vascular access requirements, and daily monitoring and maintenance of the vascular access. This team's clinical decision making was supported in real time by interactive communication with the attending intensivist. Critical care nurses, also educated in CVC maintenance, provided essential line care when critical care therapists were unavailable. A standardized CVC maintenance and insertion education program for residents, nurses, and respiratory therapists continued throughout the 4-year study. Hand washing was routinely emphasized.

Intervention: Utilizing PICCs as Part of the Comprehensive Central-Line Infection Prevention Strategy Using PICCs

Central venous pressure monitoring as an indication for open-ended PICC insertion began January 1, 2001, after the critical care practice committee reviewed published data. Thus, we examined an existing CVC (CICCs and closed-ended PICCs) database for 12 months before this date to establish baseline utilization and safety data. The 3 years after this date were designated PICC years 2001, 2002, and 2003. The intervention was the insertion and monitoring of

TABLE 1. Patient and Hospitalization Characteristics*

	Year of Insertion				
	CLIP Control	PICC Intervention			
Variable	2000 (n = 364)	2001 (n = 464)	2002 (n = 433)	2003 (n = 527)	P†
Patients					
Median age, y	72 (50–85)	67 (45–81)	68 (44–84)	68 (46–82)	0.10
Female sex	117 (32)	120 (26)	133 (31)	169 (32)	0.40
Comorbid condition					
Hypertension	133 (37)	149 (32)	145 (33)	124 (24)	0.08
Congestive heart failure	49 (13)	64 (14)	54 (12)	62 (12)	0.20
Chronic pulmonary disease	58 (16)	73 (16)	63 (14)	70 (13)	0.90
Cerebral vascular disease	15 (4)	16 (3)	20 (5)	10 (2)	0.10
Arterial vascular disease	51 (14)	48 (10)	40 (9)	42 (8)	0.10
Degenerative neurologic disease	43 (12)	58 (13)	57 (13)	59 (11)	0.70
Chronic liver disease	57 (16)	78 (17)	66 (15)	77 (15)	0.90
Chronic renal disease	38 (10)	44 (9)	40 (9)	27 (5)	0.01
Malignancy	60	62	65	66	0.60
Hospitalization					
Type of admission					
Surgical	200 (55)	241 (52)	195 (45)	263 (50)	0.10
Medical	142 (39)	200 (43)	212 (49)	227 (43)	0.08
Coronary care unit	22 (6)	23 (5)	26 (6)	37 (7)	0.60
Median maximal daily SOFA score	8 (4–14)	8 (3–13)	7 (3–13)	7 (2–13)	0.07
Antibiotics	284 (78)	349 (75)	302 (70)	321 (61)	0.02
Outcome					
Median ICU stay, d	5 (1.4–17.0)	4.2 (0.8–23.0)	4.4 (1.1–14.7)	4.2 (1.1–15.5)	0.40
Median hospital stay, d	10 (5–28)	11 (4–34)	10 (4–23)	10 (4–26)	0.30
Death	45 (12)	57 (12)	56 (13)	39 (7)	0.07

*Values are number (percentage) or median (10th to 90th percentile), unless indicated otherwise.
†*P* values denote the comparison of control year 2000 versus intervention year 2003.

TABLE 2. Infection Rate and Use of CICCs and PICCs in Study Cohort

	Year of Insertion				
	CLIP Control	PICC Intervention			
	2000	2001	2002	2003	*P**
No. patients	364	464	433	527	
CICC insertions, n (%)	309 (85)	328 (71)	194 (45)	149 (28)	<0.0001
Pulmonary artery catheters, n (% CICC)	199 (64)	179 (56)	123 (63)	82 (55)	0.30
Total PICC insertions, n (%)	240 (66)	307 (66)	460 (106)	487 (92)	<0.0001
Open-ended PICC, n (% PICC)	0 (0)	60 (20)	207 (45)	234 (48)	<0.0001
Both PICC and CICC present, n (%)	67 (18)	74 (16)	95 (22)	59 (12)	0.1
Total catheter-days	5352	5497	5883	5187	
Catheters resulting in CRBSI	8	6	4	2	0.04

Calculated infection rate per 1000 catheter-days (5 percentile − 95 percentile) for year 2000 1.0 (0.4–2.0) and year 2003 0.2 (0.3–1.0).
**P* values denote the comparison of control year 2000 versus PICC intervention year 2003.

open-ended PICCs by a dedicated high-proficiency vascular access team (i.e., critical care therapists). CICCs continued to be used at the clinician's discretion.

Peripherally Inserted Central Catheters

During the 4-year study period, both open-ended and closed-ended PICCs were used. *Open-* or *closed-ended* refers to the distal tip of the catheter. Open-ended catheters permit hemodynamic monitoring. Patients received either a double-lumen closed-ended catheter (Groshong catheter; Bard Access Systems, Salt Lake City, UT) (19- and 20-gauge lumina, 5F, 55-cm silicone catheter) or a double-lumen open-ended catheter (Arrow International, Inc, Reading, PA) (18- and 20-gauge lumina, 5F, 55-cm polyurethane catheter).

PICCs were placed at bedside within the basilic vein with ultrasonographic guidance by critical care therapists,[17] who followed standard infection control precautions[18] and provided ongoing line monitoring and maintenance. Chest radiography confirmed correct positioning of catheter tips at the junction of the superior vena cava and right atrium. Recorded data included the indication for PICC placement, anatomical site, geographic location, complications associated with placement and use, date and time of placement and removal, and placement personnel.

PICC insertion times were obtained from a random sample of 20 insertions by critical care therapists in the ICU. Insertions were timed from material setup to PICC availability.

Centrally Inserted Central Catheters

Three types of CICCs were considered during the review period: (1) 7F, 16-cm, noncuffed, triple-lumen, polyurethane-heparin–bonded CVCs impregnated with chlorhexidine gluconate and silver sulfadiazine (ARROWgard Blue; Arrow International, Inc); (2) 9F, 10-cm polyurethane introducer catheters (Arrow International, Inc); and (3) 8F, 110-cm, heparin-coated pulmonary artery catheters (Edward Life Sciences, Irvine, CA). All catheters were inserted by a board-certified intensivist or a physician under their direct supervision with or without ultrasonographic guidance at the clinicians' discretion. CICC insertion times were obtained from a random sample of 20 insertions by attending ICU intensivists and were timed from material setup to CICC availability for use.

Data Collection and Analysis

Patient demographics (e.g., age, sepsis-related organ failure [SOFA] score[19]), ICU LOS, and hospital LOS) were obtained from an ICU quality-assurance database. CVC data were obtained from a vascular access database maintained prospectively for all patients undergoing CVC placement in the ICU or intermediate care unit. We used the average of the median reported cost per CRBSI and attributable mortality to estimate cost (US $36,000 per CRBSI) and mortality (19%).[2–4]

All continuous variables were presented as median and percentile (range, 10% to 90%) and analyzed by the Student *t* test or the Wilcoxon rank sum test. Categorical variables were expressed as actual numbers as well as percentages and analyzed by the χ^2 or Fisher exact test. The control group for all comparisons was the central-line infection prevention (CLIP) year 2000 cohort. Comparison of LOS was performed with a nonparametric test of the median (number of points above median). All statistical tests were 2-tailed, and significance was accepted at $P < 0.05$. Statistical analysis was performed using JMP statistical software version 5.1.1 (SAS Institute Inc, Cary, NC).

RESULTS

Thirty-eight percent of patients required CVC placement while in the ICU or intermediate care unit. With the exception of chronic renal disease and antibiotic usage, the patient population was similar throughout the 4-year study, with a median age of 68 years and a median maximal SOFA score of 8 (Table 1). A total of 6210 CICC catheter-days and 15,709 PICC catheter-days were analyzed. More than 99% of patients had CICCs placed in the internal jugular vein, with only 1 pneumothorax and 1 carotid puncture during the study. Most PICCs (95%) were successfully placed at bedside in the upper arm (1 brachial artery complication) with 5% requiring interventional radiological placement. During the control year, no PICCs were inserted for hemodynamic monitoring compared with 48% during the last

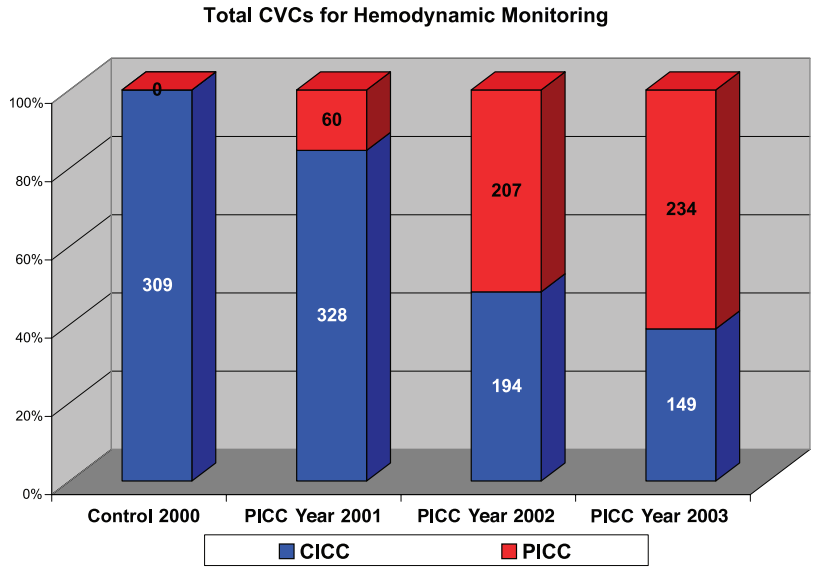

FIGURE 1. Total number and percentage of CVCs inserted centrally or peripherally in patients during the 4-year study period.

intervention year. PICC-associated upper-extremity deep venous thromboses (UEDVTs) occurred in 1% of patients and were diagnosed by ultrasound performed for clinical suspicion. Luminal occlusions requiring catheter replacement occurred in 0.4% of PICC insertions. No catheter ruptures occurred. Median procedure time for PICCs and CICCs was 30 minutes (range, 20 to 125 minutes) and 15 minutes (range, 8 to 35 minutes) ($P = 0.001$), respectively, with the longest delays resulting from radiological confirmation of tip position. The absolute number of closed-ended PICCs inserted during the study was essentially unchanged (Table 2).

Use of open-ended PICCs replaced use of CICCs such that, by the third intervention year, only 39% of CVCs inserted for hemodynamic monitoring were CICCs (Fig. 1). PICC median dwell times were not significantly changed, decreasing from 9.0 days (range, 2.0 to 23.1 days) during the control year (2000) to 8.0 days (range, 3.0 to 19.1 days) during PICC intervention year 3 (2003) (11% decrease; $P = 0.6$). There was a decrease in the number of CICC insertions and in the median dwell time from 6.4 days (range, 2.2 to 10.5 days) per line during the control year (2000) to 3.2 days (range, 1.7 to 5.9 days) during PICC intervention year 3 (2003) (50% decrease; $P < 0.001$). During this same interval, there was an 81% reduction in CRBSIs per catheter-day (from 1.6 CRBSIs to 0.3 per 1000 catheter-days; $P < 0.001$) despite no observable associated decrease in CICC catheter colonization (Fig. 2). CICC CRBSIs were completely eliminated by the final intervention year, although 2 CRBSIs resulted from PICCs. No pulmonary artery catheters were

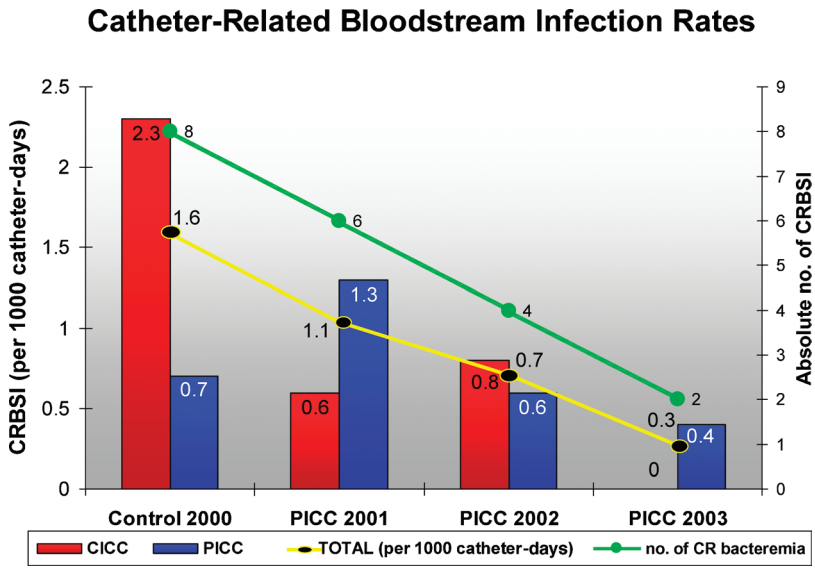

FIGURE 2. CRBSIs for centrally inserted or PICCs per 1000 catheter-days and overall. CR indicates catheter-related.

TABLE 3. Microbiologic Findings on CICC or PICC Catheters

	Year of Insertion							
	CLIP Control		PICC Insertion					
	2000		2001		2002		2003	
Organism	CICC (n = 15)	PICC (n = 4)	CICC (n = 22)	PICC (n = 15)	CICC (n = 23)	PICC (n = 8)	CICC (n = 16)	PICC (n = 9)
Catheter colonization (localized)								
Staphylococcus sp (coagulase-negative)	11	3	14	6	17	6	14	5
Staphylococcus. aureus	0	0	1	6	2	1	0	1
Enterobacter cloacae or *aerogenes*	1	0	2	1	1	0	0	0
Pseudomonas	0	0	2	0	0	0	1	0
Enterococcus	1	0	1	2	2	1	1	0
Klebsiella	0	0	0	0	0	0	0	1
Serratia	0	1	0	0	0	0	0	0
Yeast other than *Candida albicans*	1	0	1	0	1	0	0	0
C. albicans	1	0	1	0	0	0	0	2
CRBSI								
Staphylococcus sp (coagulase-negative)	6	2	0	2	1	3	0	1
S. aureus	0	0	1	3	0	0	0	0
C. albicans	0	0	0	0	0	0	0	1

the cause of a CRBSI. Coagulase-negative *Staphylococcus* species were the most common cause of bacteremia (83%) and CVC colonization (67%) (Table 3).

DISCUSSION

The Keystone ICU project has recently demonstrated that by developing a comprehensive unit-based safety program, designating and training physician and nurse team leaders, daily goals sheets, use of other interventions to reduce ventilator-associated pneumonia, together with implementing a central-line bundled intervention (5 evidence-based procedures to decrease CRBSIs), CRBSIs could be significantly reduced to a mean rate of 1.4 CRBSIs per 1000 catheter-days.[20] This study did not evaluate the relative effectiveness of the separate components of the intervention. The baseline year of our study evaluated the isolated impact of a central-line bundle similar to that suggested in the Keystone ICU study. Our comprehensive CLIP strategy resulted in a similarly low baseline CRBSI rate of 1.6 per 1000 catheter-days. We then substituted PICCs for CICCs whenever possible while still using the same comprehensive CLIP strategy. CRBSIs decreased to 0.3 per 1000 catheter-days and may have been associated with use of PICCs in these critically ill patients.

Primary use of PICCs and early transition from CICCs to PICCs decreased the duration of CICC dwell time by 50% without significant decrease in PICC dwell times. Decreasing CICC dwell times despite maintaining central venous access with PICCs was the most likely reason for elimination of CICC-associated bacteremia despite stable colonization rates. In ICUs, the reported mean CICC dwell time is 8.3 days,[21,22] and line infection rates increase significantly after 5 to 7 days.[23,24] In our study, the median CICC dwell time was 3.2 days during the final intervention year; thus, one might expect the ultimate elimination of CICC CRBSIs. This decrease from 1.6 to 0.3 CRBSIs per 1000 catheter-days occurred despite the internal jugular vein site and povidone-iodine skin preparation solution not being part of the currently recommended national guidelines.[18]

Our low rate of PICC CRBSIs is consistent with that reported elsewhere.[6,9] The choice of insertion site is important, however, because basilic vein insertions in the mid–upper arm appear less prone to dressing disruption and contamination than the flexion surface of the antecubital vein, which has a higher rate of infection.[25] We attributed the higher PICC CRBSI rate during PICC intervention year 1 (2001) to the learning curve associated with routine access and maintenance techniques during higher-acuity illness. Line infection rates decreased as bedside caregivers became more facile with urgent sterile access of PICC hub positive-pressure caps.

It is possible that the reduction in infection rate was unrelated to the use of PICCs or reduction in CICC median dwell time and was solely due to a delayed impact of the comprehensive central-line infection program. This is unlikely considering the stable personnel and mandatory use of the high-proficiency vascular access team for all central-line placements for 2 years prior to the study. No other factors, such as staffing ratios, hand hygiene, nutritional protocols, or clinical studies, changed during the study. An association between chronic renal disease and CRBSIs is suggested by the significantly lower number patients with renal disease in the last year compared with the control year (5% and 10%, respectively). This association is diminished by the 56% decrease in CRBSIs observed between the control year and second intervention year (Table 2) despite a similar number of patients having chronic renal disease (10% and 9%, respectively).

The success of the existing CLIP program and experienced practitioners account for the relatively low rate

of CRBSIs during the CLIP control year (2000). Both factors are integral to any successful intervention.[20,26–28]

Because PICCs are known to have a low rate of CRBSIs, it may be concerning that they are not used more frequently in ICUs or recommended as part of CLIP guidelines or campaigns.[29]

We found 4 barriers to use of PICCs in the ICU: insertion related, devices related, complication related, and practice related. To determine the value of adopting an aggressive PICC insertion strategy, these challenges must be evaluated.

Insertion-Related Barriers

The 2 most prominent insertion-related barriers include specialized training of the insertion team and the additional time required for insertion of a PICC versus a CICC. Our critical care therapists must demonstrate written and performance competency in CVC insertion and maintenance after undergoing didactic and simulation training. This training and the specialty team approach promote consistency in insertion and maintenance, which have been shown to decrease CRBSI rates.[26] The insertion team also virtually eliminates the need for the traditional use of fluoroscopy and interventional radiology to guide insertion, thus decreasing patient transfer–related risks and costs. Despite the team's expertise, their PICC insertions took 15 minutes longer than their CICC insertions and thus were not ideal for emergent situations. PICCs may be ideal for nonemergent or elective central vascular access, considering the elimination of insertion-related complications associated with CICCs such as pneumothorax, hemothorax, and carotid puncture.[30]

Device-Related Barriers

A common concern is the catheter itself (i.e., its number of ports and its ability to tolerate rapid, large-volume infusions). In our study, open-ended PICCs have a manufacturer-recommended maximal infusion rate of 3000 mL/h, which permits rapid-volume infusion of crystalloids. PICC flow characteristics require blood products to be transfused more slowly.[31] Newer PICCs, however, can tolerate flow rates of as much as 5 mL/s and have 3 lumens, thus minimizing the risk of catheter rupture while increasing the spectrum of uses to include contrast media injections for computed tomograms.

Complication-Related Barriers

Rupture of the PICC catheter is a potential complication, especially in the acute-care setting where urgent fluid or medication boluses are often necessary. However, none occurred during this 4-year study. Two other complications are also well known: catheter intraluminal occlusions and UEDVT. In our study, luminal occlusions requiring catheter replacement occurred in 0.4% of PICC insertions. In addition, 1% of PICCs inserted during the study were associated with DVT, similar to the incidence reported in the literature.[32,33] The incidence of UEDVT associated with PICCs reported in the literature is dramatically lower than that reported with CICCs (up to 33%).[34] This difference in incidence may be attributed to the smaller ratio of catheter size to vessel lumen for PICCs relative to CICCs.[35] Although the true incidence of subclinical deep venous thrombi may be much higher, the clinical consequences are still unknown, and further research is necessary.[36–38]

Practice-Related Barriers

Practice-related factors are perhaps the most resource-intensive barrier to more widespread use of PICCs. These factors range from the training of practitioners in PICC insertion to clinician education about the indications for, and limitations of, these devices. To justify the resources necessary for implementation of an ICU PICC practice, others have compared the costs of bedside PICC and CICC insertions (US $336 versus $407, respectively[39]). In addition, 2.1 million people are annually exposed to central-line devices in the ICU,[40–42] with a median CRBSI rate of 3.4 per 1000 central-line days,[5] resulting in 33,782 CRBSIs with an attributable mortality of up to 20% (6756 deaths) and an average cost per infection of US $36,000 (US $1.2 billion).[2–4] Assuming there is an association between the early substitution of PICCs for CICCs and the observed decrease in CRBSIs (0.3 per 1000 catheter-days), more than 6000 lives and US $1.1 billion may be saved annually in the United States with this intervention. This potential savings is justification for further research assessing the impact of PICCs on critical care vascular access practices.

Study Implications

Guidelines from the National Institutes of Health for CLIP[18] and from the Institute for Healthcare Improvement's central-line bundle are a systems-approach campaign to change behavior to decrease complications associated with hospitalization.[20,29] Early insertion of PICCs by high-proficiency vascular access teams as part of a comprehensive CLIP strategy is an innovation that may contribute to a further reduction of CRBSIs. As PICC technologies have progressed, PICCs utilization in acute-care settings has increased, but vigilance should be maintained to avoid inappropriate use and possible complications. We recommend additional studies be performed to determine a causal relationship between the use of PICCs and the reduction in bloodstream infections we observed in our critically ill population.

Study Limitations

There were 2 major limitations of this study. First, the study design (retrospective, lack of concurrent controls, and blinding) limits the ability to confirm a causal association between the use of PICCs and the reduction of CRBSIs. However, the association is strengthened by the reduction of infections correlating with the increasing proportion of PICCs utilized. Second, our study was performed at a single tertiary-care teaching institution and the patient case mix may not represent that of other practice settings.

SUMMARY

Our findings show that use of open-ended PICCs as part of a comprehensive CLIP strategy in ICUs may be associated with shorter CICC dwell times and dramatic reduction in CRBSIs. PICC CVCs may be an integral part of future best

practices in preventing CRBSIs. Further research is necessary to assess the morbidity, mortality, and financial impact of broadly implementing early PICC utilization as part of a CLIP strategy like that proposed by the Institute for Healthcare Improvement's central-line bundle.

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