Use of Simulation-Based Education to Reduce Catheter-Related Bloodstream Infections

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**Background:** Simulation-based education improves procedural competence in central venous catheter (CVC) insertion. The effect of simulation-based education in CVC insertion on the incidence of catheter-related bloodstream infection (CRBSI) is unknown. The aim of this study was to determine if simulation-based training in CVC insertion reduces CRBSI.

**Methods:** This was an observational education cohort study set in an adult intensive care unit (ICU) in an urban teaching hospital. Ninety-two internal medicine and emergency medicine residents completed a simulation-based mastery learning program in CVC insertion skills. Rates of CRBSI from CVCs inserted by residents in the ICU before and after the simulation-based educational intervention were compared over a 32-month period.

**Results:** There were fewer CRBSIs after the simulator-trained residents entered the intervention ICU (0.50 infections per 1000 catheter-days) compared with both the same unit prior to the intervention (3.20 per 1000 catheter-days) \((P = .001)\) and with another ICU in the same hospital throughout the study period (5.03 per 1000 catheter-days) \((P = .001)\).

**Conclusions:** An educational intervention in CVC insertion significantly improved patient outcomes. Simulation-based education is a valuable adjunct in residency education.

**Arch Intern Med. 2009;169(15):1420-1423**

IATROGENIC COMPLICATIONS OCCUR in 2.9% to 3.7% of hospitalized patients.1,2 In 2002, there were an estimated 1.7 million hospital-acquired infections in the United States.3 Central venous catheters (CVC) and associated catheter-related bloodstream infections (CRBSIs) are a major source of preventable adverse events in hospitals.4,5 Patients are exposed to 15 million CVC days annually in the intensive care unit (ICU), resulting in 80 000 bloodstream infections.7 Each of these infections carries an attributable mortality risk of 12% to 25% in addition to substantial marginal costs.3 In 2006 and 2007, reported CRBSI rates in a national sample of adult ICUs ranged from 1.2 to 5.6 per 1000 catheter-days.7

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Rates of CRBSI can be reduced by using patient care bundles that incorporate evidence-based guidelines to ensure strict adherence to sterile technique during CVC insertion.6,8 Mechanisms shown to decrease infectious complications of CVC insertion include education in hand washing, use of full sterile barrier technique, chlorhexidine skin preparations, reminders to remove unnecessary catheters, and avoidance of the femoral venous site.5,8-10

In academic medical centers, trainees commonly perform CVC insertions in critical care settings. Traditional education in CVC insertion usually involves learning at the bedside of actual patients without the opportunity for prior deliberate practice or skills assessment. Instruction in CVC insertion is important because traditional methods of procedural training are often inadequate,11,12 and education has been shown to reduce complications.8 A recent decision by the Centers for Medicare and Medicaid Services not to reimburse hospitals for preventable events such as CRBSI14 has highlighted the need to reduce complications related to CVC insertion.

Simulation-based training has been used in multiple areas of medical education to provide opportunities for deliberate and safe practice and shape the development of clinical skills.13 In earlier work our research group used simulation-based education to improve trainee skill in simulated and actual CVC insertion.16,17 However, the effect of simulation-based education in CVC insertion on the rate of CRBSI is unknown. The aim of this study was to determine the impact of simulation-based training in CVC insertion on CRBSI in a medical ICU (MICU).
METHODS

DESIGN

This was a study of all CRBSIs in 2 adult ICUs at Northwestern Memorial Hospital (NMH), an 897-bed tertiary care hospital in Chicago, Illinois, from August 2005 to March 2008. Monthly infection rates were compared before and after an educational intervention in the MICU, which is staffed by internal medicine and emergency medicine residents who perform daily patient care and routine bedside procedures including CVC insertion. Infection rates in a surgical ICU in which CVCs are also inserted by residents were used for comparison to exclude a hospitalwide effect. The study period began in August 2005, when patient care bundles were implemented throughout NMH ICUs, and ended in March 2008, 16 months after a simulation-based educational intervention in the MICU. The study was approved by the Northwestern University institutional review board, and all participants provided informed consent before participation.

INTERVENTION

From December 2006 to March 2008, 92 second- and third-year internal medicine and emergency medicine residents completed a simulation-based education program in CVC insertion before rotating in the MICU. Traditionally trained residents (who did not complete the simulation-based intervention) rotated in the MICU from August 2005 to December 2006 and in the surgical ICU during the entire 32-month study period. The study timeline is shown in Figure 1.

The simulation-based mastery learning program in CVC insertion is described in detail elsewhere. In brief, residents in the simulator-trained group took a baseline test (pretest) in CVC insertion using a simulator and a 27-item CVC skills checklist. Subsequently, these residents completed 2–two hour education sessions. The first hour contained a videotaped lecture on the technique, indications, contraindications, and complications of CVC insertion and a step-by-step demonstration of CVC insertion technique. Evidence-based guidelines for CRBSI reduction were emphasized (hand washing, full sterile barrier technique, chlorhexidine skin preparation, avoidance of the femoral site, and prompt CVC removal). The remaining 3 hours of education featured training with an ultrasonographic device and the opportunity for deliberate practice on the simulator with focused feedback. After training, residents underwent a posttest using the CVC skills checklist and were expected to meet or exceed a minimum passing score (MPS) set by an expert panel in both internal jugular and subclavian CVC insertion. Residents who did not achieve the MPS underwent more deliberate practice and were retested until the MPS was reached. This initial failure occurred in 7 of 92 residents (8%), who subsequently reached the MPS with less than 1 hour of additional practice time.

Traditionally trained internal medicine and emergency medicine residents attended a lecture series on bedside procedures at the beginning of the academic year and did not undergo training on the CVC simulator. Central venous catheter patient care bundles were used throughout NMH during the study period. The bundles mandate sterile technique, full barrier drapes, and insertion site disinfection with chlorhexidine, 2%, according to recommendations of the Institute for Healthcare Improvement (IHI). In the last 4 months of the 32-month study period, chlorhexidine-impregnated body-wipes were used for most patients in the MICU. There were no other infection control interventions during the study period. To determine whether changes in patient case mix might affect CRBSI rates, we used the mean Charlson comorbidity score to compare the severity of illness (based on International Classification of Diseases, Ninth Revision [ICD-9]–coded secondary diagnoses) of all patients with a CVC insertion in the MICU during the study period. Mean Charlson score before and after the intervention as well as the proportion of patients in each period with a principal diagnosis of sepsis were used to determine if there had been a change in illness severity.

MEASUREMENT

Rates of CRBSI per 1000 catheter-days were measured monthly by NMH’s infection control committee in accordance with protocols described by the National Healthcare Safety Network (NHSN), formerly the National Nosocomial Infections Surveillance System. All positive blood cultures in both ICUs were identified, and medical records reviewed by trained infection control personnel to determine if criteria for CRBSI were met. Infection control personnel determined CRBSI rates in accordance with routine NMH policies and were blind to the nature of this study and the timing of the simulation-based intervention.

DATA ANALYSIS

As used in previous CRBSI studies, and because CRBSI are rare events, multivariate Poisson regression modeling (Stata software, version 10; StataCorp LP, College Station, Texas) was used to test the likelihood of infection as a function of ICU location (MICU vs surgical ICU) and period, whether MICU patients were cared for before or after the educational intervention. The number of catheter-days was included as the exposure variable.

RESULTS

There were 3.20 infections per 1000 catheter-days (25 CRBSIs in 7809 catheter-days) in the MICU and 4.86 infections per 1000 catheter-days (22 CRBSIs in 4524 catheter-days) in the surgical ICU in the 16 months after initiation of CVC patient care bundles and before the educational intervention. During the 16-month educational intervention, when all second- and third-year residents in the MICU received simulation training, the CRBSI rate was sharply reduced to 0.50 per 1000 catheter-days (4 CRBSIs in 8060 catheter-days). However, the surgical ICU CRBSI rate remained at 5.26 per 1000 catheter-days (17 CRBSIs in 3227 catheter-days). Patients in the MICU had a significantly lower number of CRBSIs after the simulation-based educational intervention (P = .001) (Figure 2).
After simulation-based training, there was a significantly lower rate of CRBSI in the MICU than in the surgical ICU, where no trained residents rotated ($P = .001$) (Figure 2). The incidence rate ratio derived from the Poisson regression ($0.16; 95\% CI, 0.05-0.44$) indicates that there was an 84.5% reduction in the incidence of CRBSI in the postintervention MICU compared with the preintervention MICU or the surgical ICU throughout the study period. The mean Charlson score for MICU patients with CVCs actually increased significantly in the postintervention period, from 3.46 to 4.01 ($P = .009$), and the proportion of patients with a principal diagnosis of sepsis likewise increased during the intervention period from 21.6% to 29.7% ($P = .02$).

**COMMENT**

This study demonstrates that use of a simulation-based mastery education program in CVC insertion significantly reduced the rate of iatrogenic infectious complications in a MICU. These results extend our group’s previous findings that simulation-based improved CVC insertion skill in actual clinical care.\textsuperscript{16,17} Our findings also confirm the transfer of skill acquired in the simulated environment to improved patient care in CVC insertion as well as advanced cardiac life support.\textsuperscript{13} These results add to the growing body of literature documenting that simulation-based education improves the quality of care patients receive in such diverse areas as laparoscopic surgery,\textsuperscript{11} bronchoscopy,\textsuperscript{23} emergency airway management,\textsuperscript{24} and endoscopy.\textsuperscript{25}

Throughout our 32-month study, 98% of CVCs in the MICU were inserted by trainees. In the 16-month period when simulator-trained residents inserted CVCs, there was an 84.5% reduction in the incidence of CRBSI despite a rise in mean Charlson score and percentage of patients with sepsis in the postintervention period. This compares favorably with results of other studies using patient care bundles\textsuperscript{8} and chlorhexidine baths\textsuperscript{22} to reduce CRBSI. Another particularly encouraging finding from this study is the reduction in the rate of MICU CRBSI to 0.50 per 1000 catheter-days, which is lower than the reported national average.\textsuperscript{7} This suggests that simulation-based training and interventions such as patient care bundles can be used together to reduce CRBSI rates in a teaching-hospital ICU setting.

This study has several limitations. First, it was performed in a single institution and reflects a small number of CRBSIs over a relatively short time period. Second, the presence of unknown factors resulting in a reduction of CRBSI rate cannot be ruled out, despite comparison with the CRBSI rate in another ICU. However, in our lengthy discussions with clinicians, infection control nurses, and hospital staff, we could not identify any other plausible mechanism for the observed highly significant reduction in CRBSI rates. In addition, there was increased severity of illness among MICU patients with CVCs after the educational intervention. Third, compliance with patient care bundles in the ICUs was not measured. However, bundle usage was standard practice throughout NMH during the study period. The effect of simulation training may be partially explained by reinforcement of topics covered in the didactic curriculum such as prompt removal of CVCs and avoidance of the femoral site. However, the intervention was highly focused on hands-on practice of CVC inser-

![Figure 2. Monthly catheter-related bloodstream infection rates in a medical intensive care unit (MICU) and a comparison intensive care unit (ICU) before and after a simulation-based educational intervention in the MICU. The vertical line at December 2006 indicates the time that simulator-trained residents entered the MICU.](image-url)
tion, so we do not believe that the observed benefits are largely due to the didactic content of the sessions. Finally, residents were aware of their participation in a study of the effect of simulation-based training on immediate measures of CVC insertion quality such as number of needle passes, arterial puncture, and pneumothorax and may have altered their behavior as a result. However, data collection and analysis of CRBSI rates were performed by hospital personnel who were completely independent from residents and teaching faculty involved in the educational intervention, and residents were not aware that CRBSI rates were being studied.

In conclusion, this study demonstrates that a simulation-based mastery learning program in CVC insertion for internal medicine and emergency medicine residents dramatically reduced CRBSIs in a MICU. Rigorous education and assessment of procedural competence had important implications for the quality of care provided by trainees. Our results suggest that physicians in training can be important partners in quality-of-care initiatives at an academic medical center and that simulation-based education is a valuable adjunct to standard clinical training.

Accepted for Publication: May 19, 2009.
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Financial Disclosure: None reported.

Funding/Support: This research was supported by the Excellence in Academic Medicine Act, Illinois Department of Healthcare and Family Services (Dr Wayne) and by the Augusta Webster Research Award from Northwestern University Feinberg School of Medicine (Dr Barsuk).

Additional Contributions: We thank the internal medicine and emergency medicine residents who participated in this program for their dedication to education and patient care. J. Larry Jameson, MD, PhD, Douglas E. Vaughan, MD, and Charles Watts, MD, supported and encouraged this work.

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