Background The effectiveness of simulation-based training of critical care nurses in sterile techniques has not been determined.

Objective To evaluate the effectiveness of simulation-based training of critical care nurses to use sterile techniques during central vein catheterization and the effect of such training on infection rates.

Methods A prospective controlled study with 12-month observational follow-up to assess the rate of catheter-related bloodstream infections in a 23-bed medical, surgical, neurological critical care unit.

Results Forty-six critical care nurses completed assessment and training in sterile technique skills in the simulation laboratory. Performance scores at baseline were poor: median scores in each category ranging from 0 to 2 out of a maximum score of 4 and a median total score of 7 out of a maximum score of 24. After simulation-based training, nurses’ median scores in each ST category and their total scores improved significantly, with the median total score increasing to 23 (P < .01; median difference, 15; 95% CI, 14-16). After completion of the simulation-based training intervention, the mean infection rate in the unit was reduced by 85% from 2.61 to 0.4 infections per 1000 catheter-days (P = .02). The incidence rate-ratio derived from the Poisson regression (0.15; 95% CI, 0.03-0.78) indicates an 85% reduction in the incidence of catheter-related bloodstream infections in the unit after the intervention.

Conclusion Simulation-based training of critical care nurses in sterile technique is an important component in the strategy to reduce the occurrence of such infections and promote patient safety. (American Journal of Critical Care. 2014;23:40-48)
The Centers for Disease Control and Prevention (CDC) have published evidence-based guidelines for the prevention of CRBSIs.6,7 The interventions emphasize multidisciplinary efforts and several distinct practices, including training health care providers and using maximum sterile barrier precautions.6,7 A key element in these interventions is the role of the critical care nurse, who should assist and monitor the implementation of sterile steps while having the authority to halt procedures when sterile precautions have been breached. This role requires nurses to have excellent knowledge of the individual steps in sterile technique. Yet, the baseline knowledge among critical care nurses (CCNs) in sterile techniques during central vein catheterization (CVC) is currently unknown, and instruction of nurses has not been a focus of educational approaches to prevent CRBSI, with few published studies8-10 addressing the effectiveness of training critical care nurses to reduce the rate of CRBSIs while most studies have focused on training of physicians by using various methods.

Patient simulation is emerging as a valuable adjunct to traditional training methods and competence assessment in medical education including CVC.11-17 Medical simulation allows repetitive and deliberate practice in a realistic and interactive environment that minimizes risk to patients. The use of audiovisual equipment in medical simulation to record trainees’ performance gives valuable feedback and allows trainees to visualize their missteps.18 At our institution, besides the implementation of standard use of sterile techniques and the use of a procedure checklist during CVC, we implemented simulation-based training in use of sterile techniques during CVC for our physicians-in-training. Our research to date has indicated a wide variation in the skill level of medical residents in the use of sterile techniques. We further observed a decrease in rates of CRBSIs in our medical ICU, where simulation-based training was implemented to train our medical residents in sterile techniques during CVC.19

We carried out a prospective, controlled investigation to assess (1) baseline skills of CCNs in the use of sterile techniques during CVC and (2) the impact of simulation-based training on the sterile techniques skills of CCNs. In a separate observation, we assessed CRBSIs in our critical care unit (CCU) after the implementation of simulation-based training in sterile techniques for nurses.

**Methods**

**Setting and Participants**

We conducted a prospective controlled study with a simulation-based educational intervention at a university-affiliated, 450-bed urban teaching hospital with 23 medical, surgical and neurological CCU beds in May and June 2009. In a separate observation, we examined the rate of CRBSIs during a follow-up period from July 2009 to June 2010 (12 months). The study was approved by the hospital’s institutional review board (IRB#07-128). The board waived the requirement for participants to provide informed consent because the simulation-based training protocol was part of an existing departmental policy. The study was performed in a simulation environment that minimizes risk to patients. The use of audiovisual equipment in medical simulation to record trainees’ performance gives valuable feedback and allows trainees to visualize their missteps.18

At our institution, besides the implementation of standard use of sterile techniques and the use of a procedure checklist during CVC, we implemented simulation-based training in use of sterile techniques during CVC for our physicians-in-training. Our research to date has indicated a wide variation in the skill level of medical residents in the use of sterile techniques. We further observed a decrease in rates of CRBSIs in our medical ICU, where simulation-based training was implemented to train our medical residents in sterile techniques during CVC.19

We carried out a prospective, controlled investigation to assess (1) baseline skills of CCNs in the use of sterile techniques during CVC and (2) the impact of simulation-based training on the sterile techniques skills of CCNs. In a separate observation, we assessed CRBSIs in our critical care unit (CCU) after the implementation of simulation-based training in sterile techniques for nurses.
A Laerdal SimMan full body mannequin (Laerdal Medical) was used to simulate a patient undergoing sterile technique preparation during CVC. Each CCN was asked to select an internal jugular or subclavian CVC approach. The mannequin was placed in a hospital bed and dressed in a standard hospital gown. Simulation laboratory settings were described to each nurse participating in the study before the demonstration of sterile technique preparation during CVC. The nurse was asked to demonstrate the steps in sterile technique preparation during CVC according to usual practice until the step where the needle is inserted. The simulation laboratory has 2 separate areas (training area and control room) divided by a 1-way mirror. Three fixed ceiling-mounted cameras in the training area were used to capture the performances. A fourth maneuverable camera was also used to track and focus on particular actions taken by the nurse. All cameras were controlled from the laboratory’s control area, which was not visible to the study nurse. During the debriefing, the recorded videos were played back to the nurses to help them focus on areas for improvement and illustrate various teaching points about proper sterile technique. Figure 2 illustrates enrollment and study flow.

The CCU had 46 CCNs on staff. Forty-two of the 46 CCNs are full-time-equivalent nurses, and the other 4 are part-time nurses. The CCU has no travel nurses. The mean number of years of nursing experience was 12 years (range, 2-20 years). Two new full-time-equivalent nurses joined the staff during the study period and were trained in the simulation laboratory designed as an ICU/resuscitation room (Figure 1). All sessions were videotaped.
laboratory via the same assessment and training techniques used in this study. All CCNs (46 nurses) were individually contacted and scheduled to participate in the study.

**Study Procedures**

**Development of Study Materials.** Based on the CDC’s published recommendations, a previously described tool for assessment of sterile technique (see Appendix) was developed by study investigators and included the following categories: nonsterile preparation, hand washing, sterile field/supply preparation, sterile gowning, sterile gloving, and sterile draping. Each category was assigned equal weighting in the analysis and had a minimum score of 0 points and a maximum score of 4 points with an overall maximum score of 24 points.

<table>
<thead>
<tr>
<th>Points</th>
<th>Procedure step</th>
<th>Completed?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nonsterile PREP</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Brings central venous line cart to bedside and utilizes to obtain supplies, AND Compiles all necessary supplies</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Arranges supplies utilizing bedside table</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Places mask and hat before hand wash and field prep</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Instructs assistant to place hat and mask</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HAND WASH STEPS</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Washes hands (at least 20 seconds)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Instructs assistant to wash hands</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Operator must rewash hands if any nonsterile supplies are handled before gowning and gloving (if not applicable, give 2 additional points)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FIELD/SUPPLY PREP</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Uses chloraprep (1 point)</td>
<td>YES</td>
</tr>
<tr>
<td>1</td>
<td>Covers a large area (1 point)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Cleans field using sterile gloves using correct technique (violation of any of these steps loses point: using incorrect technique for placing gloves or contaminating gloves while placing, contaminating gloves once placed, failure to remove sterile gloves after field prep)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Cleans field using nonsterile gloves</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Fills flush syringes with sterile saline without contamination of kit/ syringes, AND Flushes catheter ports with sterile saline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GOWNING</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Assistant/operator opens gown maintaining sterility, AND Takes gown from wrapper—avoids touching wrapper, AND Opens gown with armholes facing operator, AND Allows gown to fall open without touching nonsterile objects</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Asks assistant to secure/tie rear of gown (if only top of gown is secured, do not give point). (Operator should utilize assistant to hold gown tie for spin and instructs assistant for gown tie to avoid contamination)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Inserts arms into gown, ensuring cuffs do not pass hands, AND Keeps hands/ arms within sterile field at all times (ie, raising arms above shoulder height while placing gown loses point)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>After final placement of gown, maintains sterility of gown</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GLOVING</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Assistant/operator opens sterile gloves and unfolds wrapper, making sure to touch only outside aspect</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Operator picks up right glove with left hand touching cuff inside of glove, AND Inserts right hand without touching outside aspect of glove or other sterile areas with glove extending over sleeve</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Uses right hand to pick up left glove, touching only outside aspect of glove, AND inserts left hand without touching outside aspect of glove or other sterile areas with glove extending over sleeve</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>After final placement of gloves, maintains sterility of gloves</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRAPING</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Assistant opens drape package in sterile fashion, does not touch blue drape wrapping (operator instructs assistant), AND Operator removes drape from package and blue wrapping in sterile fashion (ie, does not touch nonsterile outer wrapping, does not open interior blue wrapping in a manner that contaminates drape inside, maintains sterility of drape once opened)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Orient drape correctly, AND Removes cover over hole</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Places drape over patient without touching bottom aspect of drape or contaminating self, AND does not move drape once applied</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>After final placement of drape, maintains sterility of drape/field</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL SCORE</td>
<td></td>
</tr>
</tbody>
</table>

**Appendix** Sterile techniques assessment tool.
Nurses are required to be present during preparation for central vein catheterization.

A commercially available, full-size sterile drape and surgical gown (Kimberly-Clark), sterile gloves (Triflex, Cardinal Health), alcohol-based chlorhexidine 3.15% skin preparation (Chlorascrub Maxi Swabstick), and surgical hats and masks were used in the study and were similar to products used in the CCU.

All study observers who scored CCNs' performance in sterile technique were trained in and practiced in the simulation laboratory. Observers reviewed method of scoring and individual steps on the assessment tool and individually underwent an assessment of their sterile technique skills by using the study assessment tool. A standardized method of scoring was agreed upon among observers at the end of this exercise.

CRBSI Data Collection. In a separate observation, we reviewed CRBSI data. These data were collected monthly by trained, hospital-based infection control practitioners who were not study investigators. The National Healthcare Safety Network's definition was used as the basis for definition of CRBSI. The mean rate of CRBSIs in the medical, surgical, neurological CCU was compared between 12 months before and 12 months after the simulation-based study intervention (May 2008-April 2009 before the intervention and July 2009-June 2010 after the intervention). To determine whether changes in the severity of illness might affect rates of CRBSI, we compared the Acute Physiology and Chronic Health Evaluation (APACHE) II scores of patients admitted to the CCU before and after the study intervention.

Standard Procedures for Prevention of CRBSIs Implemented in the CCU Before This Study Intervention. At our institution, the CCU is staffed by a multidisciplinary team that includes internal medicine residents, surgery residents, full-time intensivists, and critical care nurses. In the CCU, residents perform all routine CVC procedures. Critical care nurses are required to be present during preparation for CVC. Before the study intervention and per CCU policy, all central venous catheters inserted nonsterilely in the emergency department are removed within 24 hours of insertion.

The central catheter bundle had already been implemented in the CCU in 2006. The hospital’s CCU had standard procedures for prevention of CRBSIs. A standardized protocol to prevent CRBSIs had been implemented throughout the hospital before the start of this study. This protocol included an emphasis on hand washing, use of maximum barrier precautions during CVC, cleaning the skin with chlorhexidine, avoiding the femoral site if possible, removing unnecessary catheters, use of a central catheter cart stocked with all the necessary supplies, following a checklist to ensure adherence to infection control practices, and empowering ICU nurses to stop CVC procedures if these practices were not being followed. Standard procedures for central catheter dressing changes were in place and unchanged during the study period. Before the study’s simulation-based intervention, the CCM nurses did not receive formal training in sterile techniques during CVC. A simulation-based training in sterile technique during CVC for our physicians-in-training was implemented before this study intervention and was in full force by February 2008. No other infection-reducing practices were implemented during the 12-month follow-up period in the CCU.

Study Interventions. Between May and June 2009, CCNs completed simulation-based assessment and training in sterile techniques with each nurse completing assessment and training in 2 phases. In phase I of this study period, each CCN individually underwent baseline assessment of her or his performance in sterile technique in the simulation laboratory. Two observers scored each nurse from behind a 1-way mirror in the simulation laboratory. In phase II of this study period, each CCN underwent an individualized debriefing on her or his baseline performance with 1 of 4 designated study investigators. The debriefer reviewed with each nurse the nurse’s baseline performance and the video-recorded demonstration in phase I, provided comments on individual steps when appropriate, and provided hands-on training and repetitive practice in sterile technique based on the nurse’s performance during phase I. Each debriefing session lasted 30 to 45 minutes.

After completion of simulation-based training, each CCN underwent reassessment of her or his ST skills. Training and reassessment took place in the previously described simulation laboratory. If disagreement between the 2 observers was apparent in either phase I or phase II, the 2 observers reviewed discrepancies and attempted to reach a consensus. If disagreement persisted, a third investigator reviewed the discrepancies and the relevant performance in the taped video and registered a final score. Phases I and II were completed in a period of approximately six weeks (May-June 2009).

Study Outcomes

The primary study outcome was the CCNs’ median score in sterile technique. The secondary outcome was the rate of CRBSIs in the CCU.
Statistical Analysis

The overall performance score for sterile technique, a maximum possible score of 24, consisted of 6 categories with each assigned a minimum score of 0 and a maximum score of 4 points. The interobserver agreement between the 2 observers who scored nurses was measured by the Cohen κ coefficient.\textsuperscript{21} The effect of simulation-based training on performance was evaluated by comparing sterile technique scores at baseline (before the intervention) with scores after the intervention by using a Wilcoxon signed-rank test. The CRBSI rate was analyzed by fitting a generalized linear model. The likelihood of infection as a function of study period (before vs after the training intervention) was examined by Poisson regression modeling, including the number of catheter-days as an exposure variable. A 2-sample t test was performed to compare mean APACHE II scores in the CCU from before to after the intervention. P values less than .05 were considered statistically significant. All statistical analyses were executed by using SAS 9.1 (SAS Institute Inc).

Results

Effects of Simulation-Based Training on CCNs’ Performance Scores

The median scores in each of the 6 sterile technique categories and total scores in study phases I and II are summarized in the Table. A total of 46 CCNs completed phases I and II of this study. Performance scores at baseline among the 46 CCNs were poor, with median scores in each sterile technique category ranging from 0 to 2 out of a maximum possible of 4 and a median total score of 7 out of maximum score of 24. After simulation-based training, CCNs’ median sterile technique scores improved significantly in each sterile technique category and in total scores, with the median total score improving to 23 out of maximum score of 24 (P < .01; median difference, 15; 95% CI, 14-16). The interobserver agreement between the 2 observers who scored CCNs was 0.99 (95% CI, 0.99-1.00; P < .001).

CRBSI Results

Figure 3 shows the mean rate of CRBSIs over time in the CCU before and after the study intervention. Before the study intervention, there were 2.61 infections per 1000 catheter-days (6 catheter infections in 2297 catheter-days) in the CCU. After study intervention, the mean rate of CRBSIs in the CCU was reduced by 85% to 0.4 per 1000 catheter-days (1 catheter infection in 2514 catheter-days); P = .02. There were 460 new CVCs before the study intervention and 492 new CVCs after the study intervention. None of the CRBSIs before or after the intervention was related to catheters placed in the femoral site or to catheters placed in the emergency department. All CVCs were assisted by a critical care nurse.

The incidence rate ratio derived from the Poisson regression (0.15; 95% CI, 0.10-0.91) indicates that the incidence of CRBSI in the CCU was reduced 85% after the training intervention compared with before the intervention. The mean (SD) APACHE II scores in the CCU tended to be higher after the intervention (23.2 [8.4] vs 22.4 [8.2]), but the difference was not statistically significant (P = .07).

Discussion

The purpose of our investigation was to assess the baseline knowledge of CCNs about the use of sterile techniques during CVC and to determine the effect of simulation-based training on their performance. At the conclusion of the training, we sought to determine the effect of our intervention on the rate of CRBSIs in the CCU. We found that CCNs’ baseline knowledge in sterile techniques was poor and improved significantly after simulation-based training in each sterile technique category we assessed and in total scores. Furthermore during the 12-month follow-up period after our intervention started, we were able to demonstrate an 85% reduction in the mean rate of CRBSIs in the CCU. To our knowledge, our study is the first published study to assess baseline performance of ICU nurses in detailed sterile techniques steps and to use simulation-based training.

<table>
<thead>
<tr>
<th>Study phase</th>
<th>Sterile technique category</th>
<th>Nonsterile preparation</th>
<th>Handwash steps</th>
<th>Sterile field/supply preparation</th>
<th>Sterile gowning</th>
<th>Sterile gloving</th>
<th>Sterile draping</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>23</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Wilcoxon signed-rank test of significance of difference between score for each sterile technique category and total score yielded a P < .01 for all.
before simulation-based training was poor despite their being “credentialed” in the procedure. In our study, the baseline performance of CCNs in use of sterile techniques during CVC was consistent with reported health care providers’ compliance rates, ranging from 16% to 81%. What was not investigated before our current study is the baseline skill of CCNs in sterile techniques and what effect simulation-based training would have on their performance. We believe that we have shown that simulation-based training is an effective technique for training CCNs in sterile techniques. Furthermore, we believe that this intervention was a key element in the significant reduction in CRBSI rate that we observed during the 12-month follow-up period in our CCU.

Although we did not randomize CCNs to different methods of sterile techniques training, we have shown previously that simulation-based training is superior to traditional training methods including the apprenticeship model (see one, do one, teach one) or video training alone. Several factors make simulation-based training the preferred approach. Simulation-based training addresses several aspects of the learning process. The process breaks down the procedure into all of its parts and then puts together the different components. The chance for learners to see their own performance on video provides a realistic view of their performance. Debriefing based on the video of the participant’s

**Figure 3** Rate of catheter-related bloodstream infections over time in the critical care unit before and after the study intervention. The area between the 2 dashed vertical lines represents the study intervention period.
own work combined with constructive feedback would therefore be a more advantageous means of education. This repetitive process with visual and verbal feedback most likely reinforces proper technique in an environment that traditional training is unable to accomplish.

In our study, we noted a significant reduction in the CRBSI rate in the CCU 12 months after the study’s training intervention started. This reduction is likely to be attributed to our study intervention because the other interventions aimed at reducing CRBSI rates, including the implementation of a simulation-based training program to train physicians rotating through the CCU, were already in place before the study’s training intervention.

Several potential limitations of our study deserve mention. First, we had the benefit of a dedicated simulation laboratory, which may not be available in other hospitals. However simulation-based training can be provided in less formal and costly settings with access to audiovisual equipment and mannequins. Second, as mentioned previously, our study was not randomized to compare different methods of teaching proper sterile techniques to CCNs. Third, although we were able to demonstrate a significant improvement in CCNs’ performance in sterile techniques following simulation-based training, we did not assess skills retention in this study. Decay in knowledge or skills may occur over time. Fourth, the reduction in CRBSI rates observed in our study after training CCNs may have been affected by several other confounders including the after effect of training of residents in the use of sterile techniques during CVC and the positive change in the overall attitude of CCU staff since the simulation-based training program was implemented, with possibly a more conscientious approach to sterility in performing such a procedure. However, because this intervention was the only one implemented in our CCU during the follow-up period, we believe that the reduction in incidence of CRBSIs is in large part due to training of our CCNs, and any behavioral change was a direct consequence of this study and similar simulation-based training implemented in the CCU in the follow-up period. Fifth, our intervention did not include training of CCNs to maintain central venous catheters after insertion.

In conclusion, simulation-based training of CCNs in sterile techniques during CVC should be considered as part of a comprehensive approach in the training of health care providers to prevent CRBSIs. Simulation-based training in CVC should be routinely used to reduce iatrogenic risk.

REFERENCES

FINANCIAL DISCLOSURES
Grant support was received from the New York State Empire Clinical Research Investigator Program (ECRIP) Project (2008).

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Simulation-Based Training for Nurses in Sterile Techniques During Central Vein Catheterization
Louis Gerolemou, Amelita Fidellaga, Keith Rose, Scott Cooper, Majella Venturanza, Adnan Aqeel, Qifa Han, James Jones, Janet Shapiro and Hassan Khouli

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