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A multitiered strategy of simulation training, kit consolidation, and electronic documentation is associated with a reduction in central line-associated bloodstream infections



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Background: Simulation-based training has been associated with reduced central line-associated bloodstream infection (CLABSI) rates. We measured the combined effect of simulation training, electronic medical records (EMR)-based documentation, and standardized kits on CLABSI rates in our medical (MICU) and surgical (SICU) intensive care units (ICU).

Methods: CLABSI events and catheter-days were collected for 19 months prior to and 37 months following an intervention consisting of simulation training in central line insertion for all ICU residents, incorporation of standardized, all-inclusive catheter kits, and EMR-guided documentation. Supervising physicians in the MICU (but not the SICU) also completed training.

Results: Following the intervention, EMR-based documentation increased from 48% to 100%, and documented compliance with hand hygiene, barrier precautions, and chlorhexidine use increased from 65%-85% to 100%. CLABSI rate in the MICU dropped from 2.72 per 1,000 catheter-days over the 19 months preceding the intervention to 0.40 per 1,000 over the 37 months following intervention ($P = .01$) but did not change in the SICU (1.09 and 1.14 per 1,000 catheter-days, $P = .86$). This equated to 24 fewer than expected CLABSIs and \$1,669,000 in estimated savings.

Conclusion: Combined simulation training, standardized all-inclusive kits, and EMR-guided documentation were associated with greater documented compliance with sterile precautions and reduced CLABSI rate in our MICU. To achieve maximal benefit, refresher training of senior physicians supervising practice at the bedside may be needed.

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Vascular catheter-related bloodstream infection (CRBSI) has been attributed to up to 28,000 potential annual deaths in the United States, at an estimated annual cost of up to \$2.3 billion per year.¹ A landmark study in 2006 demonstrated that strict adherence to a bundled practice of hand hygiene, full barrier precautions, chlorhexidine skin antisepsis, femoral site avoidance, and judicious early line removal can dramatically reduce the rate of CRBSI to nearly 0%.¹ Subsequently, in 2007 the Centers for Medicare and

Medicaid Services identified CRBSI as a preventable complication of health care and no longer reimbursed a complication of hospital stay in the United States.² As part of their 2009 National Patient Safety Goals,³ the Joint Commission advocated for widespread implementation of evidenced-based guidelines to reduce the rate of CRBSI, and this practice is now the standard of care for hospitals nationwide. Nevertheless, strict adherence to this practice has proven difficult to document and enforce.

With federal funding-based incentive for hospitals to transition over to "meaningful use" of electronic medical records (EMR),⁴ several hospitals are implementing EMR-based documentation systems to help guide practice and enforce tighter adherence to best practice standards. A recent study demonstrated that EMR-based procedure notes, including evidence-based elements of best practice for central line insertion, was linked to an increase in documented compliance.⁵ The effort to improve patient safety and reduce procedure-related complications has also led many institutions to move away from traditional, experience-based learning in real patients, toward training physicians via mannequin-based simulation. This type of "low stakes" learning can facilitate procedural skills acquisition with opportunity for constructive feedback and no added risk of patient harm.⁶ In fact, such "simulation-based" training of "resident" physicians in central venous catheter placement has now been shown to improve mastery of skills and reduce immediate complications^{7,8} and was recently linked to reduced catheter-related infections.^{9,10} We thus sought to determine whether the combined implementation of EMR-based documentation and mandatory simulation training of resident physicians in sterile technique and central line insertion would lead to an improvement in documented compliance with sterile technique and a reduction of central line-associated bloodstream infections (CLABSIs) in our intensive care units (ICUs).

MATERIALS AND METHODS

This study was approved and granted a waiver of consent after formal review by the Committee on Human Research Protections at the University of Vermont (UVM) and did not conflict with any local or national laws. The study was conducted in the ICUs of Fletcher Allen Hospital, a 400-bed academic hospital affiliated with the UVM, in Burlington, Vermont. The medical and surgical intensive care units (MICU and SICU, respectively) are each 21-bed units on adjacent but separate floors in the hospital, staffed by residents, fellows, and UVM Medical Group physicians. The MICU is an entirely closed unit, exclusively managed by a MICU team (ICU physician, fellow, and residents), who are responsible for placing all central lines. The SICU is a partially closed unit, with all critically ill patients managed by a SICU team, but some noncritical post-operative patients managed by a surgical team. The majority of central lines placed on SICU patients are placed by the SICU team or anesthesiologists in the operating room. Prior to this initiative, both ICUs utilized centralized central line supply carts and a paper-based checklist of bundled procedural protocol, both which were based on the prior work of Pronovost et al,¹ but compliance was sporadic and challenging to audit. Per routine policy, the CLABSI rates in both ICUs are monitored and reported on a monthly basis. In accordance with the Centers for Disease Control and Prevention's National Healthcare Safety Network, CLABSI was defined as a primary bloodstream infection (BSI) in a patient who had a central catheter in place within the 48 hours preceding the BSI, and cannot be directly linked to infection at another site.^{11,12} Whereas the term "CRBSI" attempts to more thoroughly link the BSI to a central catheter, it can be less sensitive and is rarely used for surveillance purposes.¹² Hence, CLABSI rates were collected continuously from January 2009 to August 2013, 18 months prior to (and including July

2010 for 19 total months) and 37 months following implementation of mandatory simulation training in central venous catheter placement. The same data collection methods and definition of CLABSI were used throughout the study period. Audits of compliance with sterile barrier precautions and EMR-based documentation were carried out once a month on cross samples of an average of 18 to 19 (± 1.25) patients per audit by the hospital's quality department for the first 2 months preceding and the first 24 months following the intervention.

During simulation training, physicians were instructed by 1 of 2 designated vascular access nurses or physicians on sterile technique and barrier precautions, which included enforcement of all caregivers in the room wearing a cap and mask, instruction on sterile gowning and "closed-sleeve" gloving technique,^{13,14} chlorhexidine antiseptic of the skin, sterile draping of the patient, and periprocedural maintenance of the sterile field.¹² Physicians were then trained by 1 of 2 physician-instructors in landmark identification, proper equipment preparation, and "Seldinger technique" for subclavian vascular access using Blue Phantom (CAE Healthcare, Sarasota, CA) neck and upper torso vascular access mannequins, followed by proper placement of a sterile, self-adherent dressing. Because of time constraints and significant overlap in steps, subclavian access was followed by review of landmarks and practice venipuncture of the internal jugular vein. Instructors developed an a priori checklist of mandatory steps adapted from Barsuk et al, previously shown to promote mastery of procedural skills.⁷ This checklist was used to guide initial demonstration of line placement and then used for competency evaluation of trainees during a supervised simulation exercise.

To minimize the number of needed steps to comply with sterile practice¹⁵ and eliminate the need for transferring equipment onto the sterile field, the hospital entered a contract with their central line kit provider to assemble custom, self-enclosed, and "complete" central line kits, including needleless port adaptors, sterile saline, and occlusive dressings (all previously separate). These kits were used for simulation training. After completion of simulation training, physicians were guided through an EMR-based procedure note, the first section of which documented compliance with "best practice" in minimizing risk of CLABSI¹² and was filled out by the nurse at the time of the procedure, and the second portion of which was completed by the physician. The documentation was not considered complete until the physician generated a procedure note, which autopopulated itself with all "check listed" elements filled out by the nurse and physician. At completion of training, the instructor signed the resident off as being competent for additional supervised training in the hospital.

The new kits, simulation training, and EMR-based documentation were all introduced as part of the initiative in July 2010. The training initiative began in July 2010 for residents entering the ICU in August 2010 and was thereafter delivered to all resident physicians 1 to 2 months before they rotated in either ICU. Over the first 3 months following July 2010, all 6 critical care fellows and 10 MICU attending physicians, underwent identical "refresher" training, including the training on closed-sleeve gloving and maintaining a sterile field. Senior SICU physicians and anesthesiologists placing catheters in the operating room and SICU did not attend the refresher training. As part of existing policy, physicians were encouraged to let clinical factors guide their own choice between subclavian or internal jugular access; femoral lines were strongly discouraged and carried a removal mandate after 24 hours.

CLABSI events were recorded monthly, and cumulative running totals were examined relative to time in months or total catheter-days. Because August 2010 represented the first month that simulation-trained residents rotated in the ICU, linear regression models of the running totals were obtained for each period before

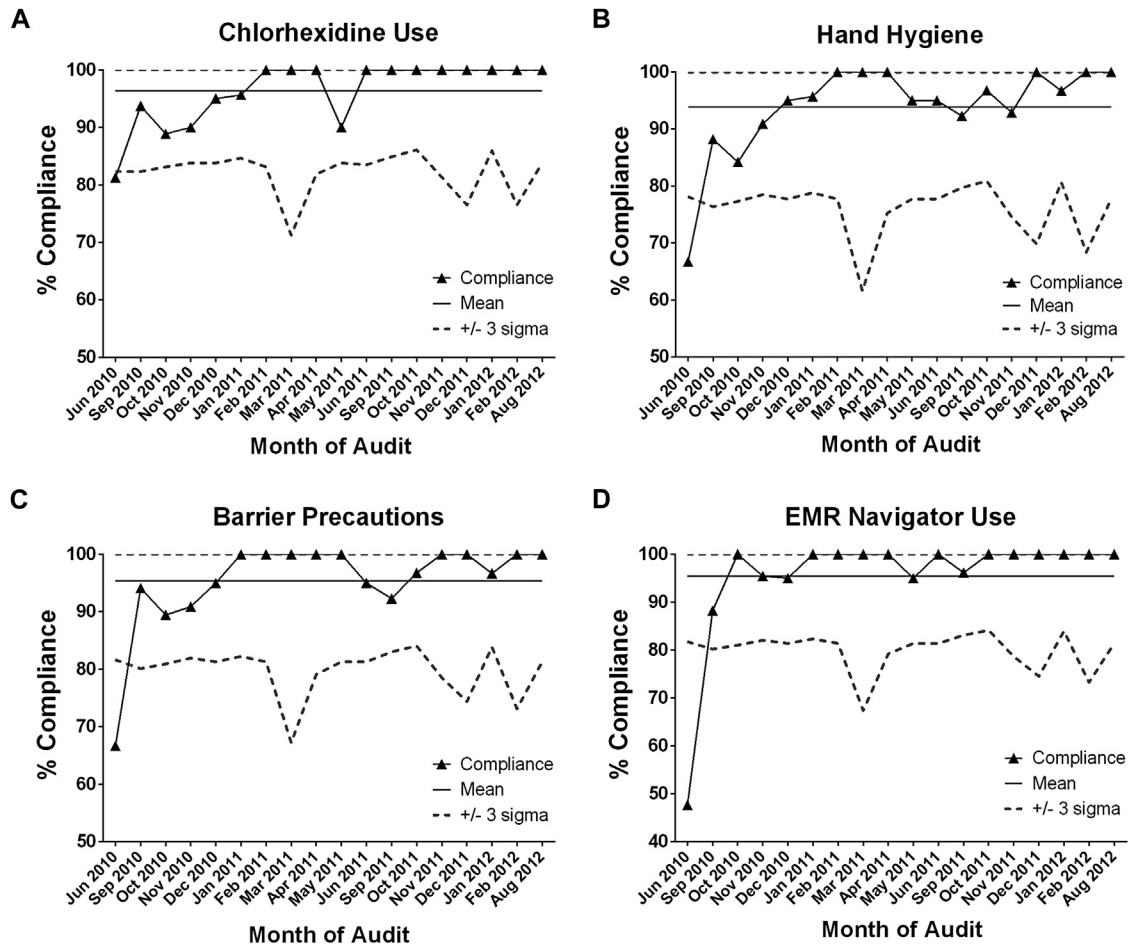


Fig 1. Control charts for compliance in the MICU and SICU with chlorhexidine use (panel A), hand hygiene (panel B), maintenance of sterile barrier precautions (panel C), and use of an electronic medical record (EMR)-based navigator for documentation of bundled precautions and procedure note (panel D). Compliance is shown in line with black triangles, mean compliance is shown in horizontal flat line, and upper and lower control limits ($3 \times \sigma$) are shown in dashed lines above and below mean. Each panel demonstrates that compliance fell out of the control limits prior to the intervention (June 2010) but remained well within control limits (and near 100%) throughout the period that followed the intervention.

and after August 1, 2010. Estimated regression slopes represented the rate of increase over each distinct period and were compared using 2-sample test with a $P < .05$ considered statistically significant. 95% Confidence intervals (CI) supplemented individual slope estimates. Nonlinear regression models using a 3 and a 4 parameter logistic parameterization formulation were also examined, but these models did not add any additional insight beyond the simpler linear regression approach. Postintervention data were analyzed first for the 18-month period that followed the intervention, from August 2010 to January 2012. Follow-up data from February 2012 through August 2013 was later added to that of the initial 18-month postintervention period and analyzed in an identical manner to evaluate for sustained intervention effect.

An institutional estimate for the added cost of a single CLABSI was determined by calculating the average cost of 37 locally hospitalized cases associated with CLABSI in 2009 and subtracting the average cost of hospitalization for matching comparison cases (matched Medicare Severity Diagnosis Related Groups [MS-DRG], gender, and age ± 5 years) not associated with CLABSI. Acceptable comparison cases could not be found for 12 out of the 37 CLABSI-associated cases. The average cost of hospitalization for the remaining 25 CLABSI-associated cases was \$103,765 per case and \$32,600 for each comparison case, leaving \$71,165 of average added hospitalization cost per case from CLABSI. Estimated cost of training 1 physician was \$289 per trainee: \$156.50 for gown, gloves, 1 kit,

and shared cost of mannequin tissues, coupled with approximately \$133 per trainee in overhead and faculty time to train 6 people over 3 hours. The estimated total cost of training 45 physicians per year came to \$13,042.50.

RESULTS

Control charts (mean $\pm 3 \times \sigma$) for compliance with barrier precautions are shown in Figure 1. Rates of compliance with documenting use of chlorhexidine skin preparation increased from 81% in June 2010 to 100% by February 2011 and remained at 100% for 10 out of the 11 following months audited (Fig 1A). Documentation of hand hygiene and sterile barrier precaution compliance both increased from 67% to 100% by February 2011 (Fig 1B and 1C). These trends followed that of compliance with EMR-based procedure notes, which increased from 48% to 100% by January 2011 (Fig 1D).

Over the 37 months that followed simulation training, the combined average CLABSI rate for both ICUs dropped from 2.03 per 1,000 catheter-days (22 events over 10,834 catheter-days) to 0.76 per 1,000 catheter-days (15 events over 19,719 catheter-days) ($P = .007$), but this was essentially all because of the drop observed in the MICU. The CLABSI rate in the MICU dropped from 2.72 per 1,000 catheter-days over the 19 months preceding the intervention (17 infections over 6,239 catheter-days) to 0.40 per 1,000 catheter-days (4 over 10,092 catheter-days) over the

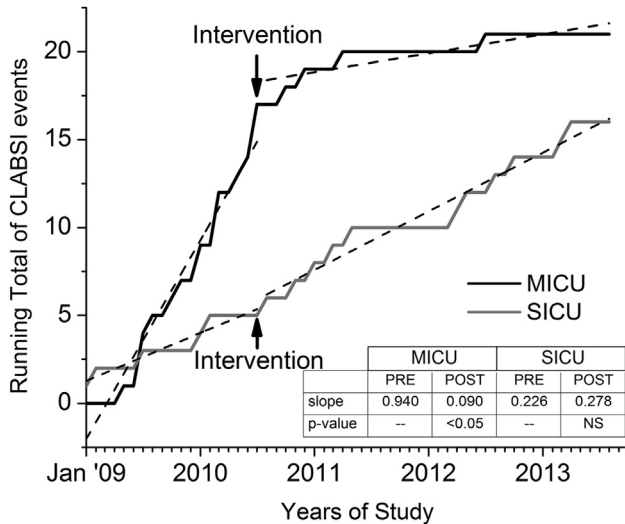


Fig 2. Cumulative running total of CLABSI events by month, over 56 months (19 months prior and 37 months following August 2010), in the MICU (thick black line) and the SICU (thick dark grey line), and linear fit slopes (dashed lines) to the portions of each curve up to and following July 2010. Arrows mark the time of the intervention on July 2010. The inset table shows that the slope of the curve changed significantly after the intervention ($P < .05$) for the MICU but not for the SICU.

37 months following intervention ($P = .01$), but CLABSI rate did not change in the SICU (1.09 and 1.14 per 1,000 catheter-days, respectively, $P = .86$).

Plotting the accumulation of CLABSI over months in the SICU and MICU between January 2009 and January 2012 (Fig 2), the final number of CLABSIs was greater in the MICU, all attributable to the lead-in period predating the intervention. However, there was a significant decline in the slope of CLABSI accumulation for the MICU after July 2010 ($P < .05$), dropping from 0.940 (95% CI: 0.848-1.032) to 0.173 (95% CI: 0.122-0.224) over 18 months, and to 0.090 (95% CI: 0.074-0.106) over 37 months, nearly a 10-fold decrease. There was no significant change in the slope of CLABSI accumulation in the SICU after July 2010, going from 0.226 (95% CI: 0.189-0.263) to 0.277 (95% CI: 0.213-0.341) over 18 months and to 0.278 (95% CI: 0.259-0.297) over 37 months.

When plotting the accumulation of CLABSI against accumulating catheter-days (Fig 3), the slope of the line for the MICU significantly declined after July of 2010 ($P < .05$), dropping from 2.81×10^{-3} (95% CI: $2.54-3.08 \times 10^{-3}$) to 6.52×10^{-4} (95% CI: $3.59-9.45 \times 10^{-4}$) over 18 months and 3.29×10^{-4} (95% CI: $2.57-4.00 \times 10^{-4}$) over 37 months. There was no significant change in slope for the SICU after July 2010, going from 9.18×10^{-4} (95% CI: $0.77-1.07 \times 10^{-3}$) to 1.20×10^{-3} (95% CI: 9.14×10^{-4} to 1.49×10^{-3}) over 18 months and 1.16×10^{-3} (95% CI: 9.40×10^{-4} to 1.10×10^{-3}) over 37 months.

DISCUSSION

Our study demonstrates that simulation-based training of physicians in barrier precautions and sterile procedural technique is associated with a reduction in the rate of CLABSI.^{9,10} However, in our study, this reduction was entirely attributable to a reduction of CLABSI in our MICU, with essentially no change in our SICU. Our study also confirms others' published work in illustrating how the use of EMR-based procedural notes, which can autopopulate themselves from nursing and physician checklists, can be associated with improved documentation of compliance with bundled sterile technique.⁵ We believe the innovation of our study is established by the dramatic reduction in CLABSI we achieved in our MICU with the combined use of fully inclusive central line kits,

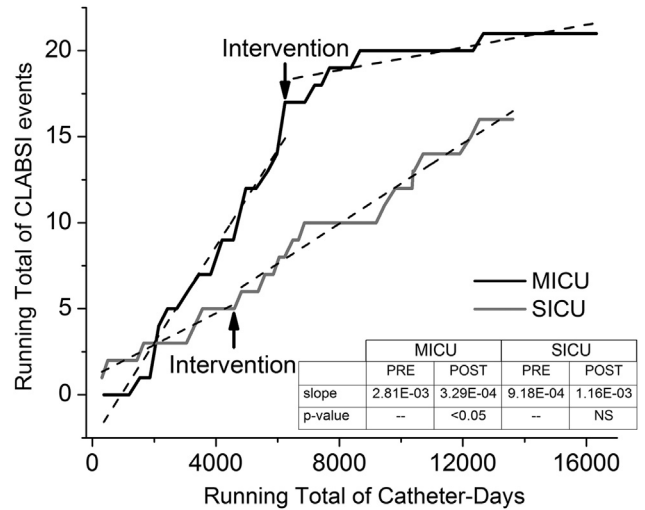


Fig 3. Cumulative running total of CLABSI events over 56 months, plotted against (corrected for) accumulating catheter-days in the MICU (thick black line) and the SICU (thick dark grey line). Linear fit slopes (dashed lines) are again shown for the portions of each curve up to and following July 2010. Arrows mark the total catheter-days for each unit at the time of the intervention. The inset table shows that the slope of the curve (CLABSI rate per 1,000 catheter-days) changed significantly after the intervention ($P < .05$) for the MICU but not for the SICU.

EMR-based documentation, and simulation training. Although we cannot say from this study which of these 3 interventions was most effective in reducing CLABSI, we think this study exemplifies the importance of incorporating several proven interventions in a multifaceted quality initiative. Our protocol is not the first of its kind to utilize a bundle of interventions¹⁶ that favors a robust outcome signal over being able to parse out which feature has the greatest treatment effect. We observed a 77% reduction of CLABSI in the MICU over the first 18 months following the intervention, comparable with the 70% and 85% rate reductions observed by other investigators.^{9,10} When examining the 37 months that followed the intervention, CLABSI rate dropped by 10-fold in the MICU, with only 1 infection documented over 2 years, representing a much greater reduction in CLABSI than that reported by others.^{9,10} In these 2 prior studies, investigators demonstrated disparate reductions in CLABSI between units by providing simulation training to resident physicians in the MICU but not in the SICU. Our study provided training to residents in both units. However, the reduction in CLABSI observed in our study remained entirely attributable to benefits observed in the MICU. We believe this finding may be partly attributable to the fact that simulation training of supervising physicians was obligatory in the MICU but not in the SICU. However, this discrepancy deserves further exploration.

Another potential explanation for the unchanged CLABSI rate in our SICU following the intervention could be the already acceptably low baseline rate of CLABSI in the SICU preceding the intervention. The preintervention CLABSI rate in our SICU (1.09 per 1,000 catheter-days) was already substantially lower than that reported by Barsuk et al (4.86 per 1,000 catheter-days)⁹ or Khouli et al (3.86 per 1,000 catheter-days).¹⁰ The average preintervention CLABSI rate in our MICU (2.72 per 1,000 catheter-days) was also lower than rates reported by these investigators yet substantially higher than that in our SICU. Thus, it may be that the higher preintervention CLABSI rate in the MICU provided greater room for improvement in this unit over the SICU. Another potential explanation for the differences observed between the units could be differences in who was primarily accountable for central line placement. All central lines in patients on the MICU service are exclusively placed by the MICU attending and resident or fellow. Central lines in our SICU are

often of mixed origin. The majority of lines are placed by the SICU team, but several are placed in the operating room prior to SICU admission.

When comparing CLABSI accumulation rates in the SICU and MICU over the first 18 months following the intervention (Figs 2 and 3), the rate of CLABSI accumulation was lower in the MICU compared with the SICU, but this did not yet reach statistical significance. Following the data over a total 37 months following the intervention (Figs 2 and 3), the significantly lower CLABSI rate in the MICU compared with that of the SICU suggests that the isolated CLABSI reduction in the MICU was not solely due to the unit's higher preintervention CLABSI rate but rather because of a greater effect of our intervention on the MICU. Because the intervention was multifactorial, we cannot say which facet of our intervention was the primary factor driving the difference, but obligatory training of senior physicians was the primary difference between the units with regard to the intervention. Our results reinforce others' findings on the importance of simulation training in a hospital's effort to prevent CLABSI. However, this is the first study of which we know to demonstrate the benefit of combining simulation training with an EMR-based procedure note and a complete and self-contained central line kit. Furthermore, we believe our results suggest that refresher training of established physicians may be needed to realize the full benefit of any similar unit-wide initiative. Whereas procedural simulation training of central line placement for novice resident physicians has been shown to improve outcomes,^{9,10} the benefit of utilizing this resource for "refresher" training of established physicians, years out from their original training, is relatively unexplored.¹⁷⁻¹⁹ Such an exercise could update and re-emphasize vital elements of sterile technique for established physicians, help reinforce the importance of documenting adherence to best practice, and provide greater uniformity in the supervision provided to resident physicians at the bedside.²⁰ We believe this added dimension of training could be vital to the success of future quality initiatives. It makes little sense to invest the financial and human resources needed to train resident physicians in procedural protocol through simulation if the training is not consistently or correctly reinforced at the bedside by supervising physicians. Anecdotally, we went back to examine our own methods to discover that prior to our intervention, many supervising SICU physicians were already using a closed-sleeve gloving technique adopted from the operating room, but many of the supervising MICU physicians were not. We believe that, without compulsory training of MICU attending physicians, we would not have seen as significant a reduction in MICU CLABSIs.

In addition to benefits in patient safety, the benefit of cost savings should not be overlooked. Had the CLABSI rate continued on its trajectory prior to our intervention in July 2010 (2.81 per 1,000 catheter-days), an estimated 28 additional CLABSI cases would have occurred in the MICU alone over the following 10,092 catheter-days, yet only 4 CLABSI events were noted in the MICU during these 37 months. Using our institutional estimate of \$71,165 in added cost per CLABSI, we estimate that the 24 fewer than expected CLABSIs following our intervention saved our own institution \$1,669,000, even after subtracting an estimated \$39,000 to train 135 physicians over these 3 years. Using other estimates based on 2002 and 2005 dollars, savings of \$23,000 to \$37,000 per CLABSI^{21,22} yield a more conservative estimate of \$513,000 to \$849,000 in savings.

To acknowledge some weaknesses of our study, our results did not account for potential differences between the units in severity of illness, the predominant purpose or site location of catheters, or the number of catheter-days per patient, all of which could influence the risk of CLABSI.²³⁻²⁵ Although CLABSI was corrected for catheter-days (Fig 3), this correction does not account for the

possibility of an equal number of catheter-days being distributed over a greater number of patients (fewer catheter-days per patient), and prior studies have demonstrated a reduced risk of CLABSI in lines removed within 7 days.²³ Because we did not monitor the actual number of lines placed, we could not determine whether the number of catheter-days per patient had any effect on our results. Because the audits for compliance with sterile barrier precautions and documentation were not kept separate for the MICU and SICU, we cannot draw any conclusions on whether differences in compliance accounted for difference in intervention effect. However, because a large number of the audits demonstrated 100% documented compliance, it is unlikely that this played a key role in the different unit outcomes.

CONCLUSION

Our study demonstrates a dramatic reduction in CLABSI in our MICU with the combined use of fully inclusive central line kits, EMR-based documentation, and simulation-based training and reinforces the multifaceted approach to quality improvement.^{26,27} Although not proven, we suspect that requisite training of established, attending physicians accounted in part for the differences in CLABSI reduction observed between our MICU and SICU and could be vital to the success of similar initiatives at other academic institutions. In an academic institution, resident physicians-in-training are often supervised by several different established practitioners. It thus makes sense that, if a technique is taught by one instructor in a controlled simulation laboratory, the behaviors learned will be rapidly lost or corrupted if not consistently reinforced in clinical practice. We thus believe that institutions should consider expanding their target intervention groups in simulation training to include both novice and established practitioners to maximize the potential for increased patient safety and health care savings.

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The corresponding author may be contacted at gil.allen@med.uvm.edu to request copies of the checklist used for simulation training and the EMR-guided checklists for nursing and physician documentation.

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