Use of simulation-based education to improve resident learning and patient care in the medical intensive care unit: A randomized trial

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Abstract
Purpose: The purpose of this study is to determine the effect of simulation-based education on the knowledge and skills of internal medicine residents in the medical intensive care unit (MICU).

Methods and Materials: From January 2009 to January 2010, 60 first-year residents at a tertiary care teaching hospital were randomized by month of rotation to an intervention group (simulator-trained, n = 26) and a control group (traditionally trained, n = 34). Simulator-trained residents completed 4 hours of simulation-based education before their medical intensive care unit (MICU) rotation. Topics included circulatory shock, respiratory failure, and mechanical ventilation. After their rotation, residents completed a standardized bedside skills assessment using a 14-item checklist regarding respiratory mechanics, ventilator settings, and circulatory parameters. Performance of simulator-trained and traditionally trained residents was compared using a 2-tailed independent-samples t test.

Results: Simulator-trained residents scored significantly higher on the bedside skills assessment compared with traditionally trained residents (82.5% ± 10.6% vs 74.8% ± 14.1%, P = .027). Simulator-trained residents were highly satisfied with the simulation curriculum.

Conclusions: Simulation-based education significantly improved resident knowledge and skill in the MICU. Knowledge acquired in the simulated environment was transferred to improved bedside skills caring for MICU patients. Simulation-based education is a valuable adjunct to standard clinical training for residents in the MICU.

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1. Introduction

Caring for patients in the medical intensive care unit (MICU) requires residents to perform several essential competencies. In a time-sensitive, emotionally, and physically stressful environment, MICU residents are expected to
manage medically complex and acutely ill patients. Residents must also acquire knowledge regarding management of complex critical illness. Exposure to critical care medicine varies widely among medical schools in the United States, and little is known about the preparation of first-year residents to provide MICU care. Anecdotal evidence from critical care faculty at our own institution indicates that first-year resident preparation varies widely, and knowledge gaps often exist. This is confirmed from findings of a survey study of resident physicians that many do not have adequate evidence-based knowledge about how to manage patients receiving mechanical ventilation [1]. Residents also expressed dissatisfaction with their training in critical care medicine and mechanical ventilation [1].

High-fidelity patient simulators are being used with increasing frequency to train health care providers in safe, controlled environments. The use of simulation technology has the potential to shape medical education and the quality of care that residents provide [2]. The American Board of Internal Medicine (ABIM) recommends that internal medicine residents receive simulator training before performing invasive procedures on patients [3]. Previous studies of simulation-based education have established its effectiveness to improve skills and reduce costs in areas such as laparoscopic surgery [4-6], endoscopy [7], advanced cardiac life support (ACLS) [8-10], emergency airway management [11], trauma resuscitation [12,13], bronchoscopy [14], obstetric emergencies [15,16], and central venous catheter insertion [17-19].

Despite widespread use of simulation, little is known about the effectiveness of simulator training as a method of preparing residents for clinical rotations, such as the MICU. Stanford University investigators developed a scoring system to evaluate management of septic shock using patient simulators and were able to differentiate the quality of resident performance in simulated scenarios [20]. In another study, medical students performed better during a simulated scenario of dyspnea if they received simulator training rather than problem-based learning [21]. However, neither study determined if simulation-based education transferred into improved clinical care.

The aim of this study was to determine the effect of simulation-based education on the knowledge and skills of first-year internal medicine residents managing critically ill patients receiving ventilator support in the MICU. We hypothesized that a simulation-based educational intervention would boost resident knowledge and skill as assessed by a bedside skills assessment checklist.

2. Materials and methods

2.1. Study design and setting

This was a prospective, cluster randomized controlled trial [22] of a simulation-based educational intervention designed to increase residents’ skills in managing critically ill patients receiving ventilator support. Data were collected for all residents at the end of their MICU rotation. All 60 first-year internal medicine residents rotating in the MICU of Northwestern Memorial Hospital, an urban university-affiliated teaching hospital, were recruited for the study from January 2009 to January 2010. Residents were randomized in groups using a random number generator by month of rotation to an intervention group (simulator-trained, n = 26) or a control group (traditionally trained, n = 34). These groups were randomly assigned to receive either traditional training and the educational intervention or traditional training alone. The number of residents in each group is not equal because the total number of residents rotating through the MICU each month varies between 4 and 6 (Fig. 1). The Northwestern University Institutional Review Board approved the study, and participants provided informed consent before participation.

2.2. Intervention

All residents spent 4 weeks in the MICU and provided patient care in teams consisting of 1 or 2 first-year residents, 1 senior resident, 1 pulmonary and critical care fellow, and 1 ABIM-certified attending physician from the Division of Pulmonary and Critical Care Medicine. Clinical MICU training included overnight call every fourth night. Teaching occurred on daily rounds and at the bedside. Traditional training included formal teaching sessions and bedside teaching at the discretion of the attending, fellow, and resident. All residents also participate in a minimum of 10 hours of didactic critical care education each year.

Intervention group residents also received 4 hours of simulation-based education 2 weeks before the start of their MICU rotation. Educational topics included circulatory shock, respiratory failure, and mechanical ventilation. Each session was led by the same faculty member, a senior member of the Division of Pulmonary and Critical Care Medicine, and a former director of the MICU. Four to 6 residents were included in each teaching session. The sessions began with a 2-hour didactic session followed by a 2-hour hands-on simulation session. All sessions took place in the Northwestern Memorial Hospital Patient Safety Simulator Center. The training program featured a life-sized human patient simulator (Medical Education Technologies, Inc, Sarasota, Fla). This simulator operates using computer software and realistically portrays many of the physiologic and pharmacologic responses observed while caring for a critically ill patient. Residents were asked to manage a rapidly decompensating patient who required aggressive resuscitation, intubation and mechanical ventilation, invasive monitoring with arterial and central venous catheters, rapid administration of pharmacotherapy, and interpretation of laboratory data and chest x-ray imaging. Residents were subsequently debriefed and received individualized feedback about their performance.
2.3. Measurements

A 14-item checklist was used as a bedside skills assessment tool (Appendix A). The checklist was developed using a modified Delphi procedure and checklist design methodology [23]. It assessed skill regarding respiratory mechanics (airway resistance, static compliance), ventilator settings (classification, assessment of auto-positive end-expiratory pressure, and description of inspiratory flow), and circulatory parameters (central venous pressure and mean arterial pressure). The checklist was reviewed for accuracy and completeness by 2 authors with expertise in MICU clinical care (TCC) and simulation-based education and checklist design (DBW). Each checklist item was listed in order and given equal weight. A dichotomous scoring scale (done correctly or done incorrectly) was imposed for each item. The checklist was piloted on a group of 15 advanced medical residents who were not study subjects to assess feasibility.

One to 3 days before finishing the MICU rotation, each first-year resident was taken individually to the bedside of an MICU patient receiving assist-control ventilation. Residents were asked to use information obtained from the patient’s ventilator and cardiac monitor to answer checklist questions. During the 12-month study period, questions were read verbatim from the checklist, and residents were not prompted. The bedside skills assessment was administered by 1 of 3 examiners (a pulmonary and critical care fellow, a pulmonary and critical care attending, or an internal medicine chief resident). To assess interrater reliability, a 40% random sample of bedside skills assessments was also scored by a second examiner who was blind to examinee status (simulator-trained or traditionally trained).

2.4. Outcome assessment

Performance on the bedside skills assessment between simulator-trained and traditionally-trained residents was compared to measure the effectiveness of the simulation-based intervention. This was performed to demonstrate whether knowledge acquired in the simulated environment transferred to the bedside of an actual patient. Secondary outcomes included results of a self-assessment questionnaire and of a satisfaction survey. Residents were asked whether they agreed with statements describing confidence in managing specific intensive care unit (ICU) scenarios, such as septic shock and respiratory failure. Responses were recorded on a Likert-type scale, where 1, strongly disagree; 2, disagree; 3, uncertain; 4, agree; 5, strongly agree. A Likert-type scale was also used to assess satisfaction with simulation training.

2.5. Statistical analysis

Demographic differences between simulator-trained and traditionally trained residents were assessed using Pearson $\chi^2$ test and 2-tailed independent-samples $t$ tests. Between-group differences on the bedside skills assessment checklist were evaluated for the 2 groups using 2-tailed independent-samples $t$ tests. Checklist score reliability was estimated by calculating interrater reliability, using the $\kappa$ coefficient [24]. Multiple regression analysis was used to assess the effect of age, sex, United States Medical Licensing Examination (USMLE) step 1 and 2 scores, prior ICU experience in medical school, and training status (simulator-trained vs traditionally trained) on resident performance on the bedside skills assessment checklist. Self-confidence differences were assessed using $t$ tests. All analyses were performed using PASW Statistics software, version 18.0 (SPSS, Inc, Chicago, Ill).
3. Results

All 60 eligible first-year internal medicine residents consented to participate in the study and completed the entire protocol. There were no significant demographic differences between residents in the simulator-trained and traditionally trained groups (Table 1).

Interrater reliability for the bedside skills assessment was very high. Across the 14 checklist items, the mean κ coefficient was 0.95. Simulator-trained residents scored significantly higher on the bedside skills assessment checklist compared with traditionally trained residents (82.5% ± 10.6% vs 74.8% ± 14.1%, \( P = .02 \)) (Fig. 2). When controlled for age, sex, USMLE step 1 and 2 scores, prior ICU rotation in medical school, and training status using regression analysis, only training status (simulator vs traditional training) remained a significant predictor of bedside skills assessment performance (\( P = .03 \)).

There were no differences in self-confidence at the end of the MICU rotation between simulator-trained and traditionally trained residents. Residents in both groups reported similar confidence managing patients with septic shock (mean, 4.17 ± 0.49 vs mean, 4.06 ± 0.44; \( P = .40 \)), acute respiratory distress syndrome (mean, 3.64 ± 0.72 vs mean, 3.74 ± 0.58; \( P = .54 \)), critically ill patients (mean, 3.46 ± 0.72 vs mean, 3.61 ± 0.70; \( P = .43 \)), and patients on mechanical ventilators (mean, 3.57 ± 0.72 vs mean, 3.65 ± 0.66; \( P = .68 \)).

Responses of the 26 simulator-trained residents on a course evaluation survey were consistently positive (Table 2). These data show that residents were satisfied with the simulator curriculum and felt that it improved their ability to perform patient care in the MICU.

4. Discussion

This study demonstrates that use of simulation-based education improves knowledge and skill among residents managing common problems in the MICU such as mechanical ventilation and invasive hemodynamic monitoring. Specifically, a standardized educational intervention improved residents’ knowledge and clinical skill as assessed by a bedside skills assessment performance (Table 2).

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### Table 1 Baseline characteristics of residents

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Simulator-trained residents, n = 26</th>
<th>Traditionally-trained residents, n = 34</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>26.7 ± 1.9</td>
<td>26.8 ± 1.5</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>7 (26.9%)</td>
<td>16 (47.1%)</td>
</tr>
<tr>
<td>USMLE step 1</td>
<td>233.0 ± 15.6</td>
<td>229.1 ± 31.0</td>
</tr>
<tr>
<td>USMLE step 2</td>
<td>249.7 ± 15.4</td>
<td>237.4 ± 31.4</td>
</tr>
<tr>
<td>Required ICU rotation in medical school, n (%)</td>
<td>8 (33.3%)</td>
<td>11 (37.9%)</td>
</tr>
</tbody>
</table>

Plus-minus values are means ± SD. Parameters did not differ significantly between groups. USMLE, United States Medical Licensing Examination.

### Table 2 Simulator-trained resident satisfaction with the simulation curriculum

<table>
<thead>
<tr>
<th>Likert scale: 1, strongly disagree; 5, strongly agree</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice with the simulator and mechanical ventilator boost my skill to perform these competencies in the MICU</td>
<td>4.31 ± 0.68</td>
</tr>
<tr>
<td>It is okay to make clinical mistakes using the model</td>
<td>4.50 ± 0.65</td>
</tr>
<tr>
<td>I receive useful educational feedback from the training sessions</td>
<td>4.31 ± 0.68</td>
</tr>
<tr>
<td>Practice with the simulator boosts my clinical self-confidence</td>
<td>4.04 ± 0.60</td>
</tr>
<tr>
<td>Simulator sessions should be a required component of residency education before the MICU rotation</td>
<td>4.41 ± 0.95</td>
</tr>
<tr>
<td>Increasing the difficulty of simulated clinical problems helps me become a better doctor</td>
<td>4.27 ± 0.70</td>
</tr>
<tr>
<td>The controlled environment in the simulator center helps me focus on clinical education problems</td>
<td>4.27 ± 0.63</td>
</tr>
<tr>
<td>Practice with the simulator has helped prepared me to perform better in the MICU rotation than clinical experience alone</td>
<td>4.00 ± 0.82</td>
</tr>
</tbody>
</table>

* Plus-minus values are means ± SD.
simulated clinical environment transfers into improved clinical skills at the bedside.

Our intervention contained a didactic component in addition to simulation-based education. Although it is possible that attending the lecture could affect resident skill, we believe that the simulation component featuring hands on practice is responsible for these results. Deliberate practice with individualized feedback is a powerful tool to boost clinical skills [26] and is much more effective than passive methods such as lectures. In other complex medical skills such as ACLS, skill retention after simulation-based educationfar exceeds that of traditional lecture-based training [10]. Similarly, basic science lectures by an experienced instructor yield inferior results to a curriculum based on the principles of deliberate practice involving hands on problem solving and feedback from an instructor [27]. As our results are consistent with earlier studies, we believe that the opportunity for deliberate practice with feedback is the reason for the effectiveness of the simulation-based curriculum in improving resident clinical skills.

Previous work has evaluated the effect of simulation-based mastery learning of central venous catheter insertion on actual patient care and demonstrated fewer needle passes when performing the procedure [28] in addition to reduced catheter-related bloodstream infections [18] and decreased hospital costs [19]. To our knowledge, there are few studies that have attempted to assess the effect of a simulation-based intervention on the quality of resident bedside patient care in the MICU. This study adds to what is known about the effect of simulation-based education for residents providing care to critically ill patients. In this study, we demonstrate that simulator-trained residents significantly improved their scores on the bedside skills assessment, reflecting an improved understanding of real-time ventilator and hemodynamic parameters. This medical education research qualifies as translational science because medical knowledge and patient care skills acquired in the simulation laboratory transfer directly to better bedside skills [29].

Although bedside skills were assessed in study subjects, this study was not designed to determine the impact of simulation-based education on outcomes such as MICU patient days, ventilator days, and patient mortality. As improved patient care is the ultimate goal of educational interventions, further study is required to assess patient outcomes such as these after simulation-based education.

New duty hour regulations from the Accreditation Council for Graduate Medical Education have the potential to impose constraints on critical care education for residents by further reducing work hours for first-year residents [30]. This is troubling given prior concerns about the effectiveness of traditional internal medicine resident education in critical care medicine apparent in national surveys of internal medicine residents [1] and critical care faculty members [31]. Simulation offers an alternative to traditional educational methods, [2] has been shown to reduce preventable complications [16,17] and costs [19] in the MICU, and is recommended by the ABIM [3]. Our results demonstrate that simulation training for first-year residents before their MICU rotation boosts clinical performance when assessed at the bedside. Residency programs may wish to consider simulation training for internal medicine residents to standardize and assess resident competency to provide MICU patient care.

Our results also show that resident self-confidence regarding managing patients in the MICU was not affected by simulation training. Untrained residents were as confident managing critically ill MICU patients as simulator-trained residents, despite lower scores on the bedside skills assessment. Although some studies have found a relationship between self-assessment and performance [1], differentiating self-confidence from actual skill is important because self-assessment does not always correlate with performance ability [32] and can be misleading.

This study has several limitations. First, it reflects the experience at 1 hospital over a relatively short period. Second, we had no pilot data for power analysis and, therefore, a limited sense of the magnitude of the intervention. A decision was made to collect data for 1 year to limit unforeseen confounders related to changes in the program, teaching, or MICU structure over time. Third, we did not assess all clinical scenarios with the bedside skills assessment, and it is possible other assessments could yield different results. Finally, we combined simulation-based education and didactic content in our intervention and cannot compare the effect of simulation to lectures alone. Further study is needed to assess the specific impact of different educational interventions on the critical care knowledge and skills of residents.

5. Conclusion

In conclusion, this study shows that simulation-based education is a feasible intervention that improves the educational experience for residents and boosts clinical knowledge and skill. In an era of increased duty hour restrictions for first-year residents, programs such as this are needed to supplement clinical experiences in critical care medicine. Further study is needed to assess additional clinical outcomes, such as length of MICU or hospital stay, rate of health care complications, and patient mortality. We believe that medical simulation is a powerful adjunct to standard clinical education for internal medicine residents providing care to critically ill patients.

Acknowledgment

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Appendix A. MICU bedside skills assessment checklist

Before testing:

- Obtain a list of MICU patients with assist control mode ventilation, central line, and arterial line
- Select random patient for each test from the list
- Make sure flow and pressure tracing are showing
- Have nurse print CVP strip
- During testing: DO NOT PROMPT THE EXAMINEE. If they do not know the answer, mark “incorrect”

Please use the ventilator to answer the following questions:

1. By using data from the ventilator please calculate the airway resistance
   Correct Incorrect
2. By using data from the ventilator please calculate the static compliance
   Correct Incorrect
3. Does the expiratory flow tracing suggest auto-PEEP?
   Correct Incorrect
4. Describe the ventilator settings (DO NOT PROMPT)
   Correct Incorrect
5. Mode
   Correct Incorrect
6. RR
   Correct Incorrect
7. VT
   Correct Incorrect
8. FiO_2
   Correct Incorrect
9. PEEP
   Correct Incorrect
10. Flow
    Correct Incorrect
11. Wave form
    Correct Incorrect
12. In this patient, what initiates the inspiratory flow?
    Correct Incorrect
13. In this patient, what terminates the inspiratory flow?
    Correct Incorrect
14. What is the pulse pressure?
    Correct Incorrect
15. What is this patient’s mean arterial pressure? (from monitor or calculated is acceptable)
    Correct Incorrect

Additional Comments:

References

Use of simulation-based education


