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The costs and savings associated with prevention of adverse events by critical care nurses☆

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Abstract
Purpose: The aim of the study was to determine the costs and savings associated with prevention of adverse events (AEs) by critical care nurses.
Materials and Methods: We performed a secondary analysis of data from 2 coronary care unit (CCU) studies that determined the incremental cost of AEs and the rate of near misses recovered by nurses during weekday, daytime shifts. For this study, we determined the nurse staffing costs and savings by averting AEs. Physicians judged the likelihood that observed near misses would have resulted in actual AEs if not initially intercepted. A sensitivity analysis was performed on the savings from preventing AEs and the costs of different nurse staffing ratios and experience levels.
Results: We observed 66 recovered near misses during 308 observation hours, with 34 (51.5%) judged to likely have reached and harmed the patient resulting in an AE if not intercepted. The annual incidence of prevented AEs extrapolated to 2296 events. Savings from prevented AEs ranged from \$2.2 million to \$13.2 million. Nurse staffing costs for the same time frame was \$1.36 million.
Conclusions: Although CCU nursing staffing costs are significant, the potential savings associated with preventing AEs is far greater. Further research is needed to identify the optimal nurse staffing ratios.

Critical care units are becoming increasingly important in providing inpatient care. Intensive care unit (ICU) bed use has increased in recent years while at the same time non-ICU inpatient use has decreased [1]. The costs for caring for ICU patients also continues to increase, consuming 13.3% of hospitalization costs and 4.2% of all national health care costs in 2000 [2].

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Table 1 Definitions

Term	Definition
Medical error	Failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim.
Recovered medical error	Medical errors, usually committed by physicians, that were identified, interrupted, and corrected by nurses. This is type of near miss.
Adverse event	Injury because of medical management rather than the underlying disease.
Preventable adverse event	An avoidable injury because of a medical error.
Near miss	An act of commission or omission that could have harmed a patient but did not cause harm as a result of chance, prevention, or mitigation. Also known as a potential adverse event.
Intercepted near miss	A medical error with the potential for harm that was intercepted before reaching the patient.
Mitigated near miss	A medical error with the potential for harm that was recovered after reaching the patient but before harm occurred, eg, a patient with atrial flutter was treated with intravenous heparin. Because of consistently very high partial thromboplastin times (PTT) over the prior day, the heparin infusion dose had been decreasing. A nurse recognized that the phlebotomies were drawn from the arm above the heparin infusion, requested a new specimen from another site, and the PTT was found to be sub-therapeutic. The heparin rate was correctly increased to achieve true therapeutic PTT levels. No thromboembolic complications occurred.
Prevented adverse events	Used in this study to identify the subset of observed recovered medical errors judged to have likely resulted in actual adverse events if the observed nurse did not intercept the error. For example, an intern wrote orders for intravenous normal saline at 100 mL/h on the wrong patient who was fluid-restricted for chronic renal failure. The nurse intercepted the error before reaching the patient, and the infusion order was reordered for the correct patient. This error was judged to have likely reached the patient if not for the nurse's action.
Nonintercepted near misses	Used in this study to identify the subset of observed recovered medical errors judged to have likely been recognized and intercepted by another nurse, clinician, or technology before causing patient harm . For example, in a patient with shock, a nurse starting a new shift recognized an incorrect preexisting order for intravenous phenylephrine at the titration range of 10 to 1000 μg/min. The order was then correctly changed to a maximum of 100 μg/min. The CCU's smart infusion pumps, if used correctly, would have warned an earlier nurse from attempting to administer the drug at the excessive rate, regardless if that nurse did not recognize and intercept the error.

Critical care patients are at increased risks for adverse events (AEs) and medical errors [3]. General interest in patient safety has grown exponentially since the 1999 Institute of Medicine report "To err is human" [4]. Attention to critical care patient safety has also drawn increased scrutiny in recent years, both in regard to the unique dangers as well as the unique opportunities for improvement in ICU care [5].

Critical care nurses provide most care for ICU patients and have a significant impact on ICU patient outcomes. A central nursing responsibility is patient surveillance and protecting patients from harm [6]. Nurses protect patients by preventing many medical errors from reaching and/or harming patients and thereby avoid or ameliorate many AEs [7]. Although nurse staffing ratios, or intensities, have received much attention, the optimal nurse-to-patient ratios in ICUs remain unclear [8].

We recently conducted studies of the incidence [3] and costs [9] of AEs in critical care units and the role of critical care nurses in recovering serious medical errors before they caused patient harm, also known as *near misses* [10]. Using these and other data, in this study, we have sought to determine the costs and savings associated with the prevention of AEs by critical care nurses. Sensitivity analyses of costs and savings were done for different levels of AE prevention effectiveness by ICU nurses on the basis of nursing staff ratios, or intensities, and experience.

1. Methods

1.1. Study site

This study is an analysis of the coronary care unit (CCU) data from the Critical Care Safety Study [3], which was conducted as part of the Harvard Work Hours and Health

Study [11], from July 2002 to June 2003 and the Critical Care Nursing Safety Net Study [10] from July 2003 to June 2004. Institutional human subject review boards approved these studies. Incident definitions, including adverse events and near misses, are provided in Table 1.

The studies were conducted in the 10-bed CCU of a 720-bed tertiary care academic hospital in New England. In addition to the full-time CCU staff, the hospital uses a pool of critical care nurses to fill vacant staffing shifts in all critical care units. The CCU had a unionized nursing staff of only registered nurses and did not use "agency" nurses who work at multiple hospitals. The mean CCU nurse-to-patient ratio was 1 to 1.1.

1.2. Incident identification and rating

In prior studies, we used a multimodal approach to detect AEs, but for this study, we only include AEs captured during direct continuous observations of CCU nurses by trained nurse researchers. The methods for detecting AEs [3] and near misses [10] in a CCU were previously described. Two physician reviewers rated incidents as to the presence, preventability, and potential or actual severity of harm from errors. We previously reported conducting 150 hours of direct observation of a mean of 2.04 nurses concurrently for a total of 308 observed nurse hours. Among 142 recovered serious medical errors, 66 (46%) were identified before resulting in harm.

In critical care units, multiple series of clinicians care for patients throughout the course of a 24-hour period. Therefore, it is unlikely that all near misses would have caused harm if the nurse did not recover the error during the study observation sessions. Some recovered errors were less likely to result in patient harm because another clinician or additional system safety checks would most likely have intercepted the error. An example would be the interception by the nurse of a physician order for a 10-fold higher rate for dopamine. With the use of smart infusion pumps, it is unlikely that the dangerous dose would have reached the patient in the event the nurse failed to intercept the original erroneous order [12].

We were unable to find evidence in the patient safety literature for estimates as to what proportion of near misses would have very likely resulted in AEs if the initial interception (or recovery) of the observed errors did not take place and reached the patient. Therefore, we rated the likelihood of harm resulting from such nonintercepted errors. Two internists, experienced in incident rating and not otherwise part of this study, evaluated the events. In addition, these physicians did not participate in previously rating the events in our earlier studies. The raters independently judged if the conditions were such that *if* the near misses were *not* originally recovered by the observed CCU nurse, the near miss would have most likely led to harm (prevented AE), would not have led to harm (nonintercepted near miss), or could not be determined. A third physician was available if consensus could not be reached but did not need to intervene. The κ statistic was used to assess interrater reliability.

1.3. Costs savings determination

Methods for determining the costs of AEs were previously described [9]. Briefly, we determined the costs of care and length of stay (LOS) from the hospital billing systems. We then determined the incremental costs and LOS for patients with adverse events matched to patients without events (controls) based on unit, preevent LOS, and preevent unit costs (as a proxy for matching on preevent severity of illness). We used a random effects linear regression model to regress patient costs incurred from the day of the event to either the day of an additional event or the day of unit discharge controlling for covariates such as age, sex, race, mortality, Diagnosis related group (DRG) weight, and APACHE II (Acute Physiology and Chronic Health Evaluation) and Charlson scores. For this study, we only used the CCU AEs. We matched 52 CCU patients having at least one AE with 183 CCU control patients. We found an AE cost $3857 ($P = .023$) and resulted in a 1.08-day increase in the LOS ($P = .003$).

Nursing salaries were based on years of clinical experience and institutional seniority or years of service. Nurse staffing salary estimates for the CCU were based on the mean nursing demographic profile and the institutional salary scales, both provided by the CCU nurse manager. Individual salaries were not disclosed. The incremental nonsalary benefit costs in the study institution were 29%.

Estimates of the cost savings associated with critical care nurse recovery of potential AEs was based on data collection conducted during weekday daytime shifts (Mondays through Fridays from 7:00 AM to 3:00 PM). Observations of nurse activities were not conducted during holidays, evenings, nights, nor weekend shifts. Therefore, our annual extrapolations of costs and savings are restricted to 260 days (52 weeks, 5 weekdays per week) and a single 8-hour shift per day or 2080 hours per nurse position per year. This compares to the total annual working hours for each nurse position of 8760 hours (365 twenty-four–hour days).

1.4. Statistical analysis

We created models for the costs and savings of prevented AEs and nurse staffing. In addition to our previously determined mean AE cost, the model provides 4 other cost ranges; 50 and 25 percentiles less cost to 25 and 50 percentiles more cost per AE. The model also provides 2 other AE prevention rates of 25% and 50% less than our findings. The study hospital is a leader in the implementation of system-based approaches to reduce preventable AEs—though comparisons with AE rates in other hospitals are not known. However, we did not model scenarios for more frequently prevented AEs to reduce bias from overestimation of the incidence of AEs.

Table 2 Predicted annual cost savings from prevented adverse events with varying event prevention rates and event costs for a 10-bed critical care unit

Adverse event costs	Rates of prevented adverse events *		
	Same rate as the observed rate	Moderate reduction in prevention rates	Significant reduction in prevention rates
	n = 2296 adverse events **	(25% lower)	(50% lower)
	($)	($)	($)
Significantly reduced costs (50% less)	4 427 836	3 320 877	2 213 918
Moderately reduced costs (25% less)	6 641 754	4 981 316	3 320 877
Actual costs ($3857 per adverse event)	8 855 672	6 641 754	4 427 836
Moderately increased costs (25% more)	11 069 590	8 302 193	5 534 795
Significantly increased costs (50% more)	13 283 508	9 962 631	6 641 754

* Rates of prevented AEs observed during weekday, daylight shifts (7:00 AM to 3:00 PM), or 260 days in a year. Cost saving predictions are provided at moderately reduced (25%) and significantly reduced (50%) AE prevention rates. We modeled these estimates on 100% census of a 10-bed unit with 10 nurses. Calculations were only based on the daylight shifts and weekdays and did not adjust for all 3 nursing shifts per day or weekends.

** A total of 66 prevented potential AEs were identified during observation of 308 nursing hours. These were judged to result in 34 AEs if not intercepted by the nurse. This resulted in a calculated annual rate of 229.6 prevented AEs per nursing position with a nurse-to-patient ratio of 1:1 or 2296 AEs for the unit. The nurse-to-patient ratio in our study was 1: 11.

The nurse staffing cost model includes the nursing experience found in the study CCU (mean of 14 years) and both moderately reduced (10 years) and significantly reduced (5 years) average experience levels that are more commonly found in other critical care settings. Our model did not include a more experienced staffing level because the study site was already quite experienced. The model also includes the study CCU's nurse-to-patient staffing ratios (1:1) as well as a moderately reduced ratio (1:2) and a significantly reduced ratio (1:3) that are commonly found in other CCUs and critical care units.

2. Results

The proportion of nonintercepted near misses that would have resulted in harm, prevented AEs, was 51.5% (34/66). The remaining incidents were rated as either unlikely to have caused a prevented AE (16/66 [24.2%]) or could not be determined as to the likelihood of harm (16/66 [24.2%]). The κ for interrater reliability was 0.62, considered good.

2.1. Costs savings of prevented adverse events and nurse staffing

Using an adjusted incidence of nonintercepted near misses likely to result in prevented AEs (34 events/308 observation hours) and then considering the 260 weekday 8-hour shifts results in a rate of 2296 prevented AEs per nurse position per year. Using our cost data for AEs, these AEs corresponded to costs of $8 855 672 annually (Table 2).

The hourly salary scale in the study institution for critical care registered nurses (RNs) with 2, 14, and 20 years of experience was $28.34, $50.91, and $54.74, respectively. The nurses in our study were very experienced with an

Table 3 Predicted annual nurse staffing costs with varying staff experience and intensities levels for a 10-bed critical care unit

Level of nursing experience *	Nurse-to-patient staffing intensities		
	Actual staffing (10 nurses)	Moderately reduced intensity (5 nurses)	Significantly reduced intensity (3 nurses)
	(1 nurse : 1 patient)	(1 nurse : 2 patients)	(1 nurse : 3 patients)
	($)	($)	($)
Significantly reduced experience (mean, 5 y)	894 559	447 279	295 204
Moderately reduced experience (mean, 10 y)	1 120 905	560 453	369 899
Actual experience (mean, 14 y)	1 366 017	683 009	450 786

* For a nurse with 14 years experience, the hourly salary is $50.91, and with benefits, (using a 1.29 multiplier) the hourly cost is $65.67. Each nurse position for 260-daytime shifts is 2080 hours. Salary and benefits per nurse position assuming a full 10-bed unit with 10 patients and 10 nurses. Salaries are not adjusted for the differential hourly rates for the weekend day shifts. These costs do not include the incremental staffing costs to account for paid time off for vacations, paid holidays, and sick days.

average of 22 years of overall nursing experience and 14 years of institutional seniority in the CCU. Using an average of 14 years seniority, the cost for staffing each RN position, including nonsalary benefits, for 260 daytime shifts was $1 366 017 (Table 3).

2.2. Sensitivity analyses for the savings and costs of prevented adverse events and nurse staffing

The costs from prevented AEs ranged from $2 213 918, assuming the cost of an AE was 50% less than our costs and the interception rate was 50% less than our rate, to a high of $13 283 508, assuming AEs cost 50% more and with an interception rate the same as our rate (Table 2). The concurrent lowest nursing costs for preventing AEs assuming staffing for a 10-bed unit with a nurse-to-patient ratio of 1:3 and a mean of 5 years nursing experience was $295 000 (Table 3).

3. Discussion

We found that nurse staffing costs under different staff conditions were less than the expected cost savings from prevented AEs. The cost-effectiveness associated with prevention of AEs by nurses in critical care units with varying nursing experience or intensities is difficult to determine because the direct impact of different nursing staffing standards on the rate of prevented AEs is unknown. However, comparing the ranges of likely savings from prevented AEs and the costs of different nursing staffing standards provides valuable perspective to this relationship. We found that the most expensive staffing model was less costly than the savings from the least expensive AE prevention model. However, we are unable to determine if increased CCU nurse staffing experience or intensities (eg, nurse-to-patient ratios of 1:1 rather than 1:2) results in cost savings. In addition, we cannot determine how "lean" a nursing staff can be (eg, ICU nurse-to-patient ratios of 1:3 to 1:4), yet still provide high quality, safe, and cost-effective care.

A 2004 Society of Critical Care Medicine study found that the average years of experience for critical care nurses working at the time of the survey to be 7 years with an average base salary of $61 087 [13]. Using a yearly workload of 2000 hours, excluding overtime or off-shift differentials, the mean hourly salary from this survey was $30.54. Compared to these figures, the study CCU had a higher salaried and very experienced staff as well as a high-intensity nurse-to-patient ratio of 1:1.

Few studies have determined the cost-effectiveness of various nurse-to-patient staffing ratios. Rothberg and colleagues [14] found that increased staffing was associated with incremental cost-effectiveness within the range of other commonly accepted interventions such as thrombolytic therapy for acute myocardial infarction. Needleman and colleagues [15] estimated the costs of increased staffing and cost savings resulted from avoided deaths, decreased complications, and reductions in LOS associated with nurse staffing levels. They found that increasing the proportion of nursing hours provided by RNs was more cost-effective than increasing the total nursing hours that include licensed practical nurses and RNs.

Nurse staffing intensity in ICUs depends on many factors, especially the level of patient acuity. However, significant hospital-to-hospital variation exists. A 2001 report of 52 California hospitals found ICU staffing intensity ranges of 1 RN for every 0.5 to 5.3 patients with an average of 1.6 [16]. A 2002 national hospital survey reported an average ICU nurse-to-patient ratio of 1:2, but 7.4% and 11% of hospitals reported 1:3 to 1:4 ratios during the day and night shifts, respectively [17].

Previous studies in surgical critical care settings have demonstrated the relationship of nurse-to-patient staffing ratios to lengths of stays. Amaravadi and colleagues [19] found that reducing nurse-to-patient ratios from 1:1 or 1:2 to 1:3 or less was associated with a 20% to 39% increased LOS [18]. Central venous catheter-associated bloodstream infections have been found to increase in surgical ICU patients as the nurse-to-patient ratio falls from 1:1 to 1:2 and lower [20]. Abdominal aortic surgical patients have been found to be at greater risk for postoperative complications (relative risk, 1.7), especially pulmonary insufficiency (relative risk, 4.5), if cared for in ICUs with nurse-to-patient ratios of 1:3 to 1:4 rather than 1:1 to 1:2 [21]. Unplanned extubations in a multidisciplinary pediatric ICU were 4 times more likely if patients are cared for by a nurse assigned to 2 patients rather than one patient [22].

In addition to nurse staffing intensities, nursing experience is also important in patient safety. In a recent qualitative study of strategies used by nurses to recover errors in an ED, nursing experience was considered very important in supporting patient safety. Characteristics of experienced nurses that increased the likelihood of recovering near misses included confidence, assertiveness, patient advocacy skills, surveillance skills, strong critical thinking skills, and a strong knowledge base [23].

Errors of omission have recently received attention as important, but less well-studied or understood, causes of patient harm [24,25]. Errors of omission are particularly challenging to recover because, unlike commission errors, they are often less visible. Experienced critical care nurses may also be more likely to recognize these errors.

Our case finding was based on observational research conducted only during daytime weekday nursing shifts. Extrapolations of those findings to all shifts and days of the week is challenging. There are several likely reasons that the rate of prevented AEs would be expected to be lower during evening, night, and weekend shifts. Firstly, fewer invasive procedures, interventions, and orders occur during nights and weekends and therefore create less frequent opportunities for medical errors. Secondly, the experience of nursing staff is often decreased during the evening and night shifts. Finally, weekend and evening/night shifts are more frequently filled with per diem or part-time staff from a pool of critical care nurse rather than full time CCU staff. Both the less experienced staff and the part-time staff may be less effective in preventing AEs.

This study has several limitations. It was conducted in a single CCU in an academic medical center, so that the results may not be generalizable to other types of settings or critical care units. Hospitals with less experienced nurses or a significant proportion of agency critical care nurses may not accrue the same level of success for the recovery of serious errors found in our study. Our point estimate determination of the rate of prevented AEs, the recovered medical errors that would likely have resulted in AEs if not originally intercepted by the observed CCU nurse, has not been validated in other studies. The nursing staff costs in the study CCU are likely higher than in most hospitals because of our CCU's high experience levels and the higher nursing salaries in New England urban settings.

Cost-effectiveness studies in critical care are just emerging, primarily because until recently there have been few evidence-based studies of effective ICU interventions [26]. As a specific example, whereas activated protein C for patients with severe sepsis falls within the accepted cost-effectiveness ranges, less is known about other costly interventions such as 24-hour ICU intensivist staffing.

Finally, whereas prior research has demonstrated that increased nurse staffing intensity reduces costly AEs and is even associated with lower mortality rates [27], the cost savings will accrue differently to hospitals vs payers depending on the payment arrangement. However, with current reimbursement models, hospitals that expend more resources for better nurse staffing may not directly benefit financially. Developers of future pay-for-performance models including nursing-sensitive outcome measures should consider attempting to differentially reward hospitals that demonstrate better patient outcomes. In addition, hospitals embarking on investments in improving safety must often choose from among a variety of costly interventions. Examples of such interventions include computerized order entry, pharmacist staffing in ICUs, bar-coded medication administration, and rapid response teams. Institutional decisions for the allocation of limited resources to increase nurse staffing and how intensely to increase staffing must be put into the context of these competing and, in some cases, proven interventions.

In conclusion, in addition to improved patient outcomes, the financial savings associated with adverse event prevention may support the business case for investing in better nurse staffing standards for acutely ill patients. Further evidence is needed to define optimal staffing models that not only improve patient outcomes but may also be cost-effective.

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