Costs of adverse events in intensive care units*

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Context: **Iatrogenic injuries are very common in critically ill adults. However, the financial implications of these events are incompletely understood.**

Objective: **To determine the costs of adverse events in patients in the medical intensive care unit and in the cardiac intensive care unit.**

Design, Setting, and Patients: **We performed a matched case-control analysis on data collected during a prospective 1-yr observation study (July 2002 to June 2003) of medical intensive care unit and cardiac intensive care unit patients at an academic, tertiary care urban hospital. A total of 108 cases were matched with 375 controls in our study.**

Main Outcome Measures: **Costs of care and lengths of stay were determined from hospital billing systems for patients in the medical and cardiac intensive care units. We then determined the incremental costs and lengths of stay for patients with adverse events compared with patients without events while in the intensive care unit. Costs were truncated for patients with a second adverse event on a subsequent day during the intensive care unit stay.**

Results: **For 56 medical intensive care unit patients, the cost of an adverse event was $3,961 ($p = .010$) and the increase in length of stay was 0.77 days ($p = .048$). This extrapolated to annual costs of $853,000 for adverse events in the medical intensive care unit. Similarly, for 52 cardiac intensive care unit patients, the cost of an adverse event was $3,857 ($p = .023$), corresponding to $630,000 in annual costs. On average, patients with events in the cardiac intensive care unit had an increase of 1.08 days in length of stay ($p = .003$).**

Conclusions: **Patients who require intensive care are especially at risk for adverse events, and the associated costs with such events are substantial. The costs of adverse events may justify further investment in prevention strategies. (Crit Care Med 2007; 35:2479–2483)**

KEY WORDS: patient safety; adverse events; iatrogenic injuries; cost

The 1999 Institute of Medicine report, *To Err is Human* (1), highlighted the problem of iatrogenic injuries, estimating that 44,000–98,000 deaths per year were due to medical errors. Although some controversy surrounds these estimates, there is general consensus that many complications are common, costly, and avoidable (2–4). However, relatively few data about the costs of adverse events are available. Such economic data could guide institutional investments in patient safety improvement efforts.

Critically ill patients tend to incur higher rates of errors and harm from errors than patients in general care. Several factors probably cause this increase in risk, including multiple medications, the need for rapid decision making, and severity of illness with resultant decrease in individual resilience to buffer errors (5, 6).

The U.S. study that provided perhaps the best estimate of total healthcare costs for patients with all types of adverse events was the Colorado–Utah study (7). The investigators determined that in 1996 dollars, total costs were $348 million, corresponding to 4.8% of *per capita* healthcare expenditures in these states (7). Most other studies relating to adverse event costs addressed specific categories of adverse events, for example, adverse drug events (ADEs) or nosocomial infections. A study carried out in an urban tertiary care hospital determined an increased cost of $2,262 per ADE, whereas a second study in two urban tertiary care hospitals determined a cost of $2,595 per ADE and $4,685 per preventable ADE (3, 8). These estimates extrapolate to $5 billion in additional annual national healthcare costs from ADEs alone.

To further understand the financial consequences of adverse events in critically ill patients, we undertook this study. In specific, we sought to determine the additional costs and lengths of stay associated with adverse events for patients in the medical intensive care unit (MICU) and cardiac intensive care unit (CCU) of one academic, urban tertiary care hospital.

METHODS

This study is an analysis of data from the Critical Care Safety Study (CCSS), which was conducted as part of the Harvard Work Hours and Health Study from July 2002 to June 2003 (6, 9). Data were collected during fifteen 3-wk intern rotation periods distributed through the 12 months, including eight MICU and seven CCU rotations. Institutional human subjects review boards approved these studies.

Study Sites and Data Collection. The Critical Care Safety Study, as previously described, was conducted in the ten-bed MICU and ten-bed CCU of a 720-bed tertiary care academic hospital. Adverse events were defined as any

***See also p. 2637.**

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detectable injury due to medical management rather than underlying disease. These adverse events were further classified as preventable or nonpreventable, based on whether they were avoidable. Adverse events were detected by a combination of direct continuous observation, voluntary and solicited reports, a computerized ADE detection monitor, and guided implicit chart abstraction by trained research nurse. All incidents were independently reviewed by two physicians.

Controls. There were a total of 611 patients with 633 unit admissions studied during 315 days. We found 184 adverse events in 116 patients, whereas there were 497 patients in the same units without events (i.e., potential controls). We excluded one case because of missing data and attempted to find controls for the remaining 115 cases. Ultimately, we were able to match 108 patients with 379 controls according to the following protocol. We matched patients with adverse events to controls based on location (i.e., MICU or CCU), pre-event length of stay (i.e., control admission date had to be within 14 days of case admission date and unit length of stay for each control had to be longer than the time from unit admission to adverse event for the case), and pre-event unit costs (i.e., average direct variable costs from unit admission to event date for each control had to be within $1,750 of direct variable costs from unit admission to event date for each case). Pre-event costs were used as a proxy for matching on pre-event severity of illness. If a case matched with more than four potential controls, we selected four controls for each case using random sampling. A given patient could act as a control for more than one case.

Cost Data. Data regarding costs were obtained from the hospital's TSI database (Transition Systems, Boston, MA), an activity-based costing system that evaluates costs based on actual resources utilized in performing a specific activity. From this database, we obtained charges, actual variable costs, actual fixed costs, actual direct variable costs, and actual direct fixed costs. For the purposes of these analyses, we used total actual costs, which we obtained by summing actual variable costs and actual fixed costs.

Statistical Analysis. If a patient experienced two events on the same day, we counted this as a single event for the purpose of the analysis due to data constraints because our cost data were compiled on a daily basis, precluding any distinction between costs associated with two events that occurred on the same day. This adjustment affected eight of 56 patients in the MICU and four of 52 patients in CCU.

For all analyses, we truncated costs either at the time of an additional adverse event during the unit stay or at the time of discharge from the unit. We truncated costs in the cases of second events to distinguish costs associated with the initial adverse event from later events. Truncating costs at the time of the second event may underestimate the costs of the first event because some patient costs after the second event may still be attributable to the first event. If a patient did not have a second event during the unit stay, we uniformly truncated costs at the time of discharge from the unit. Although costs for events likely continued to accrue after unit discharge, many other factors contribute to overall hospital costs, most importantly, length of stay, thereby decreasing our statistical ability to determine costs attributable to the adverse event.

After using the matching algorithm described above, 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 on: the marker for an adverse event, age, gender, race, payer type, Charlson Index, Acute Physiology and Chronic Health Evaluation (APACHE) score, diagnosis-related group weight at discharge, whether the patient was alive at time of discharge, and pre-event total costs. We used the log of total patient costs in the regression because the distribution of raw patient costs was skewed. The regression analysis was performed using the natural logs of costs and length of stay; however, we present raw values to provide a sense of magnitude.

To estimate the annual costs in each unit from adverse events, we first determined the total number of patient admissions to each unit per year, the number of patients included in the study, and the number of adverse events identified during the study. From these data, we were able to estimate the average annual number of adverse events per unit. This number was multiplied by the cost of an adverse event in each unit to determine total annual costs.

RESULTS

A total of 108 cases (56 in the MICU and 52 in the CCU) were matched with 375 controls (192 in the MICU and 183 in the CCU); 44 of the MICU cases and 40 of the CCU cases matched with at least four controls. For the remaining MICU cases, four matched with two controls, eight matched with one control, and five were unable to be matched. In the CCU, five matched with three controls, one matched with two controls, six matched with one control, and two remained unmatched. Therefore, a total of seven cases were not matched because there were no controls with an appropriate pre-event length of stay. In addition, the pre-event unit cost variable had to be increased to $9,000 to find matches for four cases (three in the MICU and one in the CCU).

In these 108 patients, 159 adverse events were identified. Of these events, 52 (32.7%) were significant, 79 (49.7%) were serious, 24 (15.1%) were life-threatening, and four (2.5%) were fatal. The complications most commonly involved the respiratory system (n = 37, 23%), cardiovascular system (n = 25, 16%), or were infectious (n = 22, 14%). The most common type of respiratory complication was pneumonia (24 cases, nine due to aspiration and seven ventilator associated) and acute respiratory failure (six cases). The cardiovascular complications included eight arrhythmias, seven hypotensive episodes, and two cardiac arrests. There were 11 catheter-related blood stream infections. Of these 159 adverse events, 70 (44%) were preventable and 65 (41%) were due to medications (ADEs).

Of these 108 patients, 97 patients (48 in the MICU and 49 in the CCU) had a single event on the day of their first event, whereas 11 patients (eight in the MICU and three in the CCU) had two events on the day of their first event. As explained in the methodology section, it was impossible to separate costs for two events occurring on 1 day due to the structure of the cost data. In addition, eight of 56 cases in the MICU and four of 52 cases in the CCU had costs truncated due to multiple events.

Table 1 depicts the demographic variables of interest for the cases compared with controls for each intensive care unit. In the MICU, there was no statistical difference between cases and controls in terms of age, sex, race, insurance status, in-hospital mortality, Charlson Index, APACHE score, diagnosis-related group weight, pre-event length of stay, or postevent length of stay. In the CCU, cases tended to be men and white more often than control patients.

Table 2 compares total resource utilization of patients with adverse events compared with controls in both the MICU and CCU. MICU cases had longer lengths of stay in the intensive care unit, higher costs in the intensive care unit, and higher costs from unit admission to event, but not overall increased length of stay or total hospital costs. In the CCU, cases had longer lengths of stay in the hospital, intensive care unit, and in routine care and higher total hospital costs compared with control patients.

We next compared the resource utilization after the adverse event in both the MICU and CCU (Table 3). Cases in the MICU had higher costs in the intensive care unit after adverse events compared

Table 1. Demographics of patients in the medical intensive care unit (MICU) and cardiac intensive care unit (CCU)

Variable	MICU Patients			CCU Patients		
	Cases	Controls	p Value[a]	Cases	Controls	p Value[a]
Patients, n	56	192	N/A	52	183	NA
Age in years, mean	60.3	63.6	.21	66.3	66.2	.95
Female, n (%)	22 (39.3)	103 (53.6)	.059	17 (32.7)	89 (48.6)	.042
Nonwhite, n (%)	14 (25.0)	62 (32.3)	.30	5 (9.6)	43 (23.5)	.028
Uninsured, n (%)	4 (7.1)	33 (17.2)	.063	3 (5.8)	16 (8.7)	.49
Died in hospital, n (%)	28 (50.0)	77 (40.1)	.19	14 (26.9)	40 (21.9)	.44
Charlson index, mean	2.88	3.15	.44	2.83	2.53	.31
APACHE score, mean	22.14	21.19	.41	20.58	17.97	.066
DRG weight, mean	3.33	3.31	.98	4.26	4.73	.50

NA, not applicable; APACHE, Acute Physiology and Chronic Health Evaluation; DRG, diagnosis-related group.

[a]Two-tailed test probability that difference in mean values between cases and controls is not statistically significant.

Table 2. Total resource utilization in the medical intensive care unit (MICU) and cardiac intensive care unit (CCU)

	MICU			CCU		
	Cases	Controls	p Value	Cases	Controls	p Value
Length of stay, days						
Total	21.0	20.8	.943	21.3	14.3	.006
In intensive care unit	10.6	7.8	.032	8.5	6.5	.045
In routine care	10.4	13.0	.295	12.8	7.8	.040
Unit admission to event	4.4	3.2	.079	2.8	2.3	.190
Hospital costs, $						
Total	68,371	56,681	.208	68,263	47,206	.010
In intensive care unit	45,424	28,040	.005	37,268	29,180	.076
In routine care	22,946	28,641	.357	30,995	18,026	.070
Unit admission to event	22,075	12,661	.009	14,076	10,798	.094

Table 3. Resource utilization after the adverse event (AE) in the medical intensive care unit (MICU) and cardiac intensive care unit (CCU)

	MICU			CCU		
	Cases	Controls	p Value	Cases	Controls	p Value
Length of stay after AE, days						
Total	11.6	12.3	.690	14.4	10.6	.053
In intensive care	6.2	4.6	.091	5.7	4.2	.089
In routine care	5.4	7.7	.139	8.7	6.3	.202
Event to unit discharge or second event	5.0	4.3	.25	4.6	4.0	.300
Hospital costs after AE, $						
Total	32,519	30,639	.712	43,467	31,993	.095
In intensive care	23,349	15,380	.040	23,192	18,381	.248
In routine care	9,169	15,259	.054	20,275	13,611	.213
Event to unit discharge or second event	19,304	14,403	.087	18,183	17,373	.765

with controls. There were no statistically significant differences for CCU patients.

In linear regression analyses, controlling for age, sex, race, in-hospital mortality, primary insurer, diagnosis-related group weight, Charlson Index score, APACHE score, and pre-event costs, we found that patients in the MICU had an increased length of stay of 0.77 day ($p = .048$) and increased costs of $3,961 ($p = .010$) from the day of the first adverse event to unit discharge or additional adverse event on a subsequent day (Table 4). The corresponding numbers for patients in the CCU were an additional 1.08 days ($p = .003$) and costs of $3,857 ($p = .023$).

Finally, we projected annual costs related to adverse events for the two units. The annual costs are estimated to be $853,000 in the MICU and $630,000 in the CCU, for a total of $1,480,000 per year.

DISCUSSION

In this study, we found that adverse events cost $3,961 in the MICU and $3,857 in the CCU, resulting in almost a million dollars of costs in the MICU and approximately half a million in the CCU per year, for total additional costs of $1.5 million per year at Brigham and Women's Hospital, a 720-adult-bed hospital with both a ten-bed MICU and CCU. Patients with events were also associated with an increase in length of stay, accounting for much but not all of the increase in costs. These findings demonstrate that adverse events are costly in intensive care units, suggesting that interventions that reduce their frequency are important not only from the patient safety perspective, but also because they may have a financial effect.

The annual costs for our hospital were $1.48 million for two ten-bed units. In 2000, there were an estimated 20.7 million patient days nationwide in critical care units at nonfederal hospitals, including medical, cardiac, burn, surgical, and other specialty intensive care units (10). If all 20.7 million inpatient days were at CCUs, total costs may be estimated at $5.8 billion, whereas if they were all in MICUs, total costs may be estimated at $7.2 billion. This number needs to be carefully interpreted because hospitals may vary greatly in rates of adverse events, severity of adverse events, distribution of inpatient days among units, and associated costs.

Halpern et al. (10) estimated national costs per day of critical care medicine to be $2,674 in 2000. The calculated costs of adverse events in this study are greater than these national costs per day. Clearly, these numbers must also be interpreted carefully given the elapse of 2 yrs before the start of this study and the fact that the estimate of costs per day of critical care medicine was made nationally. In addition, our study assessed the incremental cost of an adverse event, whereas Halpern et al. (10) estimated the cost per day in the intensive care unit.

As noted earlier, relatively few studies have evaluated the costs of all adverse events either in the hospital or in partic-

Table 4. Adjusted paired analysis

	Cases	Controls	Difference	*p* Value
MICU				
LOS after AE to unit discharge or second event, days	3.83	3.06	0.77	.048
Costs after AE to unit discharge or second event, $	12,635	8,674	3,961	.010
CCU				
LOS after AE to unit discharge or second event, days	3.70	2.62	1.08	.003
Costs after AE to unit discharge or second event, $	13,246	9,389	3,857	.023
Combined				
LOS after AE to unit discharge or second event, days	3.79	2.83	0.96	<.000
Costs after AE to unit discharge or second event, $	13,276	8,943	4,332	<.000

MICU, medical intensive care unit; LOS, length of stay; AE, adverse event; CCU, cardiac intensive care unit.

Data are mean values and are adjusted for pre-event unit costs, age, sex, race, in-hospital mortality, primary insurer, diagnosis-related group weight, Charlson Index score, and Acute Physiology and Chronic Health Evaluation score.

ular units. More studies have evaluated costs of specific types of adverse events, such as ADEs, ventilator-associated pneumonia, and catheter-related blood stream infections. A study in 1993 combined data from Brigham and Women's Hospital and Massachusetts General Hospital (10a). It estimated that ADEs in the MICU cost $3,369 per event and resulted in $449,209 of costs per year. These numbers are somewhat smaller than the numbers found in the present study, even after controlling for inflation. This is likely because the earlier study focused only on ADEs, an important and common type of adverse event but only a minority of adverse events; 41% of the cases included in our study were ADEs. Previous studies of ventilator-associated pneumonia and catheter-related blood stream infections have found the attributable costs due to these adverse events to approximate $12,000 (11) and $10,000 to $56,000 (12, 13). Other types of events and different severity of events are undoubtedly associated with different costs.

Many previous studies, including the one at our institution, relied on charges instead of costs; costs were not available at the time of the previous study (3, 10). Some of these studies employed charge-to-cost ratios; however, there is likely increased accuracy gained in analyzing actual costs, which are becoming increasingly available (14). Other previous studies utilized expert review and estimates (8). Again, although there is extremely useful knowledge gained from these estimates, empirical data will likely be more accurate.

It should be noted that at the time of this study, several interventions to improve patient safety were already in place in our units, including the use of computerized physician order entry, pharmacist participation in clinical rounds, an emphasis on building a just culture, intensivist staffing, and low patient-to-nurse staff ratios approaching one to one. Despite these interventions, we found many adverse events with substantial associated incremental costs. Hospitals with fewer safety interventions in place may have higher rates of adverse events. Since the completion of this study, several additional patient safety interventions have been implemented. These include smart intravenous pumps, structured sign-out protocols, Web-based incident reporting, barcode medication administration, and a redesigned house staff work schedule (9, 15, 16). It is likely that these interventions have further reduced our rates of adverse events.

Our study has several limitations. Our sample size was small, precluding interesting subanalyses such as costs associated with preventable vs. nonpreventable adverse events or varying costs across different severities of events. In addition, some patients had more than one event on the first day with an event. Because our costing system calculated costs per day, we were not able to determine the incremental cost of each event. It is important to note that we only included costs until either the second event or the time to unit discharge to optimize the sensitivity of our analysis. Additional costs are likely incurred for many patients during the remainder of their hospital stay and, for some, even after discharge due to longer-term morbidity.

Ideally, we would have matched cases and controls on all major characteristics that could affect patient cost of care, leaving only the case's experience of an event as the difference between a case and its matched controls. However, because the patient pool was not large enough to do such a matching, many covariates affecting costs, such as age, death of the patient, and resources used in-patient care (i.e., diagnosis-related group weights), had to be included in the regression. This may result in an underestimate of costs attributable to an adverse event. For example, the regression results showed that the death of a patient while in the hospital is associated with increased costs of care, regardless of whether the patient experienced an event. However, if the adverse event caused death, then some of the costs that the regression attributes to a patient's death really should be attributed to the adverse event that caused the death. A similar bias may result from the inclusion of diagnosis-related group weights in the regression because those weights reflect the intensity of patient care and resource utilization during the patient's entire length of stay, some of which may have resulted from the adverse event.

CONCLUSIONS

The costs of adverse events in intensive care units are substantial. This is likely in part due to the frequency of adverse events in intensive care due to the complexity of care and the severity of patients' illnesses combined with the expensive ramifications of mistakes in this setting. The findings of our study further justify investments in quality improvement and patient safety strategies, particularly for intensive care units.

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