Intensive Care Unit Nurse Staffing and the Risk for Complications after Abdominal Aortic Surgery

ORIGINAL ARTICLE

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Eff Clin Pract. 2001;4:199-206.

CONTEXT. We previously found that length of stay in the intensive care unit (ICU) after abdominal aortic surgery increased when fewer ICU nurses were available per patient. We hypothesized that having fewer nurses increases the risk for medical complications.

OBJECTIVE. To evaluate the association between nurse-to-patient ratio in the ICU and risk for medical and surgical complications after abdominal aortic surgery.

DESIGN. Observational study.

SETTING. All nonfederal acute care hospitals in Maryland.

DATA SOURCES. Information about patients came from hospital discharge data on all patients in Maryland with a principal procedure code for abdominal aortic surgery from 1994 through 1996 (n = 2606). The organizational characteristics of ICUs were obtained by surveying ICU medical and nursing directors in 1996 at the 46 Maryland hospitals that performed abdominal aortic surgery. Thirty-nine of the ICU directors (85%) completed the survey.

EXPOSURE. Surgery in hospitals with fewer ICU nurses (in which each nurse cared for three or four patients) compared with hospitals with more ICU nurses (in which each nurse cared for one or two patients).

OUTCOME. Proportion of patients who developed postoperative complications.

RESULTS. Seven hospitals with 478 patients had fewer ICU nurses, and 31 hospitals with 2128 patients had more ICU nurses. Patients in hospitals with fewer nurses were more likely than patients in hospitals with more nurses to have complications: 47% vs. 34% had any complication, 43% vs. 28% had any medical complication, 24% vs. 9% had pulmonary insufficiency after a procedure, and 21% vs.13% were reintubated (P < 0.001 for all comparisons). After adjustment for patient, hospital, and surgeon characteristics, having fewer versus more ICU nurses was associated with an increased risk for any complication (relative risk, 1.7 [95% CI, 1.3 to 2.4]), any medical complication (relative risk, 2.1 [CI, 1.5 to 2.9]), pulmonary insufficiency after procedure (relative risk, 4.5 [CI, 2.9 to 6.9]) and reintubation (relative risk, 1.6 [CI, 1.1 to 2.5]).

CONCLUSION. Having fewer ICU nurses per patient is associated with increased risk for respiratory-related complications after abdominal aortic surgery.

Edited by Steven Woloshin, MD, MS

See related editorial on pages 223–225.

Patients in intensive care units (ICUs) require substantial nursing care. Nevertheless, nurse staffing varies widely among ICUs, and the optimal nurse-to-patient ratio remains unclear.[1] Efforts to reduce costs of hospital care have resulted in decreased nurse-to-patient ratios; however, the effects of this reduction on quality of care have not been well evaluated, causing concern among patients, providers, and

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TABLE 1
Postoperative Complications Considered in the Analysis*

COMPLICATION	ICD-9-CM CODE	DEFINITION
Medical complications		
Pulmonary insufficiency	5184	Acute lung edema
	5185	Pulmonary insufficiency after surgery
	5188	Respiratory failure not otherwise specified
Tracheal reintubation	9604†	Reinsertion of endotracheal tube
Cardiac complications after a procedure	9971	Cardiac complications during or resulting from a procedure
Acute renal failure	584‡	Renal failure developing during the hospitalization
Septicemia	038‡	Bloodstream infection
Acute myocardial infarction	410‡	Perioperative heart attack
Cardiac arrest	4275	Cardiorespiratory arrest
Surgical complications		
Surgical complications after a procedure	9981	Hemorrhage or hematoma complicating surgery
	9982	Accidental puncture or laceration during procedure
	9983	Disruption of surgical wound (dehiscence)
Surgical E codes	E8700	Puncture, perforation, or hemorrhage during surgery
Reoperation for bleeding	3941†	Control of hemorrhage after vascular surgery
	3949†	Other revision of vascular surgery
	3998†	Control of postoperative hemorrhage not otherwise specified

**A panel of four critical care physicians created the list of complications before the start of the study. The complications represent the most important complications of abdominal aortic surgery. All complications were coded as dichotomous variables. ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification.*
†*Codes are ICD-9-CM procedure codes.*
‡*Includes all subsequent codes.*

policymakers.[2–5] Previous studies that measured nurse staffing at the hospital level found an association between nurse staffing and specific complications, including postoperative infections and pulmonary complications.[6–8] However, nurse staffing varies within hospitals. By evaluating the impact of nurse staffing at the unit level rather than the hospital level, we may be more likely to identify an association between nurse staffing and patient outcomes. Because critically ill patients in an ICU require close nursing surveillance to ensure early detection of potential adverse events and prompt intervention to prevent morbidity, a reduction in ICU nurse staffing may negatively affect quality and outcomes of care.

Previously, we reported that a decreased ICU nurse-to-patient ratio was associated with a significant increase in length of stay in the ICU for patients who had abdominal aortic surgery in Maryland.[9] We hypothesized that the increased length of stay may be due to a greater risk for medical complications. We therefore sought to evaluate the association between the ICU nurse-to-patient ratio and risk for medical and surgical complications.

Methods

Data

After obtaining approval from our institutional review board, we gathered nonconfidential patient data from the Uniform Health Discharge Data Set. This data set, which is maintained by the Maryland Health Services Cost Review Commission (HSCRC), contains information on all patients discharged from the 52 nonfederal, short-term-stay hospitals in Maryland. We obtained information on all patients 30 years of age or older who were discharged from a Maryland hospital between January 1994 and December 1996 with a principal procedure code for abdominal aortic surgery (International Classification of Diseases, Ninth Revision, Clinical Modification [ICD-9-

TABLE 2
Hospital Characteristics

CHARACTERISTIC	HOSPITALS WITH FEWER ICU* NURSES (*n* =7)	HOSPITALS WITH MORE ICU NURSES (*n* =31)
Median beds, *n* (range)	248 (109–467)	282 (76–850)
Median abdominal aortic surgeries performed annually, *n* (range)	95 (3–122)	85 (5–266)
Routine extubation in the operating room	29%	39%

**ICU = intensive care unit.*

CM] code 3844 for resection of abdominal aorta with replacement and ICD-9-CM code 3925 for aorto-iliac–femoral bypass). We excluded 9 patients who were younger than 30 years of age, all of whom had had an injury to a blood vessel (ICD-9-CM code 902).

Exposure: ICU Nurse Staffing

In December 1996, we mailed a survey to the ICU directors at the 46 Maryland hospitals recorded in the HSCRC database as having performed abdominal aortic surgery in our target period. These directors were asked to have the ICU nurse managers complete the information about ICU nurse staffing. The details of our survey methods are published elsewhere.[9]

The survey included questions about the average ICU nurse-to-patient ratio during the day and evening; possible responses were 1:1, 1:2, 1:3, or 1:4. On the basis of the few responses with ratios of 1:1 and 1:4 and data from exploratory analyses, we created a dichotomous variable: We considered nurse-to-patient ratios of 1:1 or 1:2 as "more ICU nurses" and ratios of 1:3 or 1:4 as "fewer ICU nurses." Because our previous study demonstrated that ICU nurse staffing during the day rather than the evening was associated with ICU length of stay, we limited the current analysis to ICU nurse staffing during the day.[9]

Outcome: Complications

We obtained information about complications and comorbid conditions by using one of the 14 secondary diagnoses and procedure codes included in the HSCRC database. The list of complications was created before the start of our study by a panel of four critical care physicians who used a Delphi process to determine the most important complications. In our previous analysis, several of these complications were found to be associated with in-hospital mortality or length of stay, which supports construct validity.[9]

In this paper, we focused on medical and surgical complications that were independently associated with in-hospital mortality. These complications are defined in **Table 1**. Although the discharge diagnosis codes we used do not distinguish between complications and comorbid conditions, the medical diagnoses listed here are for acute problems and are therefore more likely to represent complications than comorbid conditions.

Covariates

Hospital Characteristics

We assessed the number of hospital beds and the volume of aortic surgery performed during the study period by each hospital and each surgeon in the database.

Patient Characteristics

We included variables for patient age (in years), sex, and race (white or nonwhite).

Comorbid Conditions

We used the Romano–Charlson comorbidity index to identify potentially important comorbid conditions.[10–13] Instead of using a single comorbidity index in our analysis, each disease in the index was included as a separate variable.

Severity of Illness

To account for severity of illness, we classified patients as having a ruptured (ICD-9-CM code 441.3) or nonruptured aneurysm and used the nature of admission field, coded at the time of admission, to identify each case as elective, urgent, or emergent (Dardik A. Personal communication. 1998).[14]

Statistical Analysis

We performed a descriptive analysis of patient characteristics, in-hospital mortality, hospital length of stay, days in the ICU, and rates of medical and surgical complications for patients with more versus fewer ICU nurses. Using the patient as the unit of analysis, we performed bivariate analysis with simple logistic regression to evaluate the association between the ICU nurse staffing (independent variable) and each of the complications (dependent variables).

We then performed a multivariate logistic regression to evaluate the independent association between ICU nurse staffing and each of the complications. In each of these models, we adjusted for patient age (in years), sex, race (white or nonwhite), nature of admission (emer-

TABLE 3
Patient Characteristics

CHARACTERISTIC	HOSPITALS WITH FEWER ICU* NURSES (*n* =478)	HOSPITALS WITH MORE ICU NURSES (*n* =2128)
Mean age ± SD, *yr*	68 ± 10	68 ± 10
White patients	89%	89%
Men	66%	69%
Ruptured aneurysm	8%	9%
Nature of admission		
Elective	71%	66%
Urgent	11%	13%
Emergent	18%	21%
Cormorbid conditions†		
Previous myocardial infarction	11%	13%
Mild diabetes mellitus	14%‡	11%
Chronic obstructive lung disease	12%	10%
Any cancer	4%	4%
Chronic renal disease	3%	4%
Severe diabetes mellitus	3%	3%
Mild liver disease	1%	1%
Dementia	1%	1%
Metastatic solid tumor	0%	0%
Severe liver disease	0%	0%
Operation performed by high-volume provider		
Hospital with >36 cases/yr	51%‡	67%
Surgeon performing >8 cases/yr	22%‡	42%
Utilization		
Hospital length of stay, median (range), *d*	8 (0–130)	8 (0–171)
ICU length of stay, median (range), *d*	3 (0–112)‡	2 (0–118)
Inpatient mortality rate (95% CI)	8% (6.0%–11.2%)	7% (6.0%–8.1%)

**ICU = intensive care unit.*
†Comorbid diseases considered in this analysis were those in the Romano–Charlson comorbidity index.[4]
‡P <0.05.

gent vs. elective and urgent vs. elective), type of aneurysm (ruptured or nonruptured), and comorbid conditions (yes or no for each of the 10 diseases in the Romano–Charlson index). Because routinely extubating patients in the operating room was independently associated with increased length of stay in our original study,[9] we included this variable in our multivariate model. We also included terms for surgeon volume and hospital volume.

We modeled hospital and surgeon volume as dichotomous variables. Using Lowess smoothing curves,[15] we defined low volume as fewer than 36 cases per year for hospitals and fewer than 8 cases per year for surgeons. (A Lowess smoothing curve is a method used to identify cut-points in data by obtaining a locally weighted regression. The output of this analysis is a graph with volume on the x axis and probability of

death on the y axis. The cut-points for high and low volume were chosen from these graphs.)

Patients in our study were naturally clustered within hospitals, which artificially decreased our variance estimates. We used hierarchical models that took such clustering into account.[16] For the bivariate and multivariate analyses, we converted the odds ratios obtained from logistic regression to relative risks by using the method described by Zhang.[17] All reported *P* values are two-tailed. *P* values were considered significant if they were less than 0.05. We used STATA 6.0 software (Houston, Texas) to perform all calculations.

Results

Patient and ICU nurse staffing data were available for 38 of the 46 hospitals in this study. Seven hospitals had fewer ICU nurses and 31 hospitals had more ICU nurses. Both groups included small and large hospitals and low and high surgical volumes (**Table 2**). The practice of routinely extubating patients in the operating room, which was associated with an increased risk for reintubation and postoperative pulmonary complications in our previous study,[9] was not related to nurse staffing.

Table 3 shows the characteristics of patients who had surgery in hospitals with fewer versus more ICU nurses. Demographic characteristics and severity of illness did not differ between patients in either nurse staffing model. Mild diabetes mellitus was the only comorbid disease that occurred significantly more often in patients in ICUs with fewer nurses. Mild diabetes mellitus was associated neither with ICU length of stay in our previous study[9] nor with risk for any complication or medical complication in this analysis. Patients in hospitals with fewer nurses were less likely to be treated in low-volume hospitals and to undergo surgery by a low-volume surgeon. The in-hospital mortality rate did not statistically differ between the two nurse staffing models.

Overall, 47% of patients treated in hospitals with fewer ICU nurses and 34% of patients treated in hospitals with more ICU nurses had at least one complication. Patients treated in hospitals with fewer ICU nurses were also more likely to experience any medical complication (43% vs. 28%) (**Table 4**). Pulmonary insufficiency (24% vs 9%) and reintubation (21% vs 13%) were more common among patients treated in hospitals with fewer ICU nurses. Nurse staffing did not affect the risk for a surgical complication.

The crude analysis showed that having fewer ICU nurses was associated with a significantly increased risk for having any complication, any medical complication, pulmonary insufficiency after a procedure, cardiac complications after a procedure, and reintubation (**Table 4**). In multivariate analysis adjusted for patient characteristics and hospital and surgeon volume, having fewer nurses was associated with an increased risk for any complication (relative risk, 1.7 [95% CI, 1.3 to 2.4]), any medical complication (relative risk, 2.1 [CI, 1.5 to 2.9]), pulmonary insufficiency after procedure (relative risk, 4.5 [CI, 2.9 to 6.9]), and reintubation (relative risk, 1.6 [CI, 1.1 to 2.5]).

In our previous analysis, daily rounds by an ICU physician was related to risk for complications.[9] After we added daily rounds by an ICU physician to the multivariate analysis used in this study, all regression coefficients remained unchanged, suggesting that ICU nurse staffing has an independent effect.

Discussion

We found that having fewer versus more ICU nurses per patient was independently associated with an increased risk for medical complications, including pulmonary insufficiency after a procedure and reintubation. Although we cannot establish a causal relationship by using this type of analysis, our findings have face validity and support our hypothesis that ICU nurse staffing is associated with risk for pulmonary complications. Nurses who care for three or more patients in the ICU may have less time than nurses who care for one or two patients to devote to patient care—especially preventive measures, such as postoperative pulmonary care.

This study adds to our previous work in evaluating how the organization of ICU care is related to clinical and economic outcomes. We previously found that no daily rounds by an ICU physician is associated with increased risk for acute renal failure, septicemia, cardiac arrest, reintubation, and platelet transfusion.[9] In the current study, daily rounds by an ICU physician and ICU nurse staffing during the day were not significantly correlated; addition of daily rounds by an ICU physician to the multivariate analysis did not change the regression coefficients. These results suggest that ICU nurse staffing is associated with risk for specific complications independent of ICU physician staffing. Optimal ICU organization should probably address both physician and nurse staffing.

Our study has several limitations that may affect our conclusions. First, because the study is essentially a retrospective analysis, we cannot establish a causal relationship between ICU nurse staffing and complications. Nonetheless, our findings are consistent with clinical experience that nurse staffing can affect pulmonary complications. Second, coding of complications and

TABLE 4

Percentage of Patients with Complications, Crude and Adjusted Relative Risks*

COMPLICATION	PATIENTS WITH COMPLICATION		RELATIVE RISK (95% CI)‡	
	HOSPITALS WITH FEWER ICU NURSES (*n* = 478)	HOSPITALS WITH MORE ICU NURSES (*n* = 2128)	CRUDE	ADJUSTED
Any complication	47%	34%	1.4 (1.2–1.5)	1.7 (1.3–2.4)
Any medical complication	43%	28%	1.5 (1.4–1.7)	2.1 (1.5–2.9)
Pulmonary insufficiency after procedure	24%	9%	2.6 (2.1–3.2)	4.5 (2.9–6.9)
Reintubation	21%	13%	1.5 (1.3–1.8)	1.6 (1.1–2.5)
Cardiac complications after procedure	15%	10%	1.4 (1.1–1.7)	1.3 (0.8–1.8)
Acute renal failure	6%	4%	1.3 (0.8–1.9)	1.6 (0.9–2.7)
Septicemia	4%	3%	1.4 (0.8–2.1)	1.9 (0.9–3.9)
Acute myocardial infarction	4%	3%	1.5 (0.8–2.4)	1.5 (0.9–2.2)
Cardiac arrest	2%	1%	1.4 (0.6–3.0)	1.7 (0.7–4.7)
Any surgical complication	10%	11%	0.9 (0.6–1.4)	0.7 (0.4–1.5)
Surgical complications after procedure	8%	9%	0.9 (0.6. –1.2)	1.0 (0.6–1.4)
Surgical E codes	1%	0%	2.2 (0.4–10.5)	–§
Reoperation for bleeding	2%	3%	0.8 (0.4–1.6)	1.2 (0.4–3.5)

**For definitions of complications, see the Methods section. ICU = intensive care unit.*
‡*Adjusted for patient characteristics and hospital and surgeon volume.*
§*Insufficient data to conduct analysis.*

comorbid diseases in the HSCRC database may not be as accurate as the coding of the principal procedure.[18] Because the percentage of patients with comorbid conditions (with the exception of diabetes) were similar, there does not appear to be systematic differences in coding of comorbid diseases at hospitals with more or fewer ICU nurses. Therefore, misclassification of comorbid diseases probably did not significantly bias our results. It is also unlikely that misclassification of complications biased our results. We reviewed a random sample of 25 medical records from one hospital and found that coding of complications associated with in-hospital mortality was 96% accurate. We helped establish construct validity for coding of complications by evaluating only complications that were independently associated with in-hospital mortality.[19] In addition, bias from coding of complications was probably minimal, since the association between nurse staffing and pulmonary complications is consistent with that in previous studies.[6] Despite the potential problems with coding, our analysis based on discharge data and survey data allows us to evaluate the association between health care organizational characteristics and outcomes.[20–23]

Third, we did not use a systematic scoring system, such as The Acute Physiology and Chronic Health Evaluation (APACHE) II that requires medical record review to adjust for severity of illness.[24] We classified patients as having ruptured or nonruptured aneurysms and elective, urgent, or emergent admissions, and the coding for these variables was found to be more than 98% accurate.[25] Patients who have abdominal aortic surgery are unique because the variables for ruptured versus nonruptured aneurysm and elective, urgent, or emergent admission seem to account for severity of illness relatively well, as evidenced by the odds ratios for in-hospital mortality in our original study.[9] Fourth, we did not adjust for differences in pre-ICU care, including surgical approach and type of anesthesia, and post-ICU care. However, we did adjust for hospital volume and used multilevel modeling that may account for some of these differences. Nevertheless, differences in pre- and post-ICU care, including nursing care on the

regular surgical floor, could have affected some of our results.

The fifth limitation is the validity of our measure of nurse staffing. The ICU nurse-to-patient ratio is a relatively crude measure of nursing surveillance; it is a complex variable that may be affected by staff mix, experience, training, certification, fatigue, and nursing workload. Nonetheless, nurse-to-patient ratio is easy for managers to understand and act on, and our survey provided a unit-level measure of nurse staffing that might be more accurate than hospital-level measures. From the patients' and physicians' perspective, nurse-to-patient ratio may be a measure of the perception of the adequacy of nurse staffing. Random misclassification of either the exposure or the intervention biases a study toward the null. Nurse-to-patient ratio may be a relatively imprecise measure of nursing surveillance and as such, may result in random misclassification of exposure, biasing the study to the null. Had we used more detailed measures of nursing surveillance, our findings may have been even stronger. Our findings warrant further investigation to determine how these other measures of nursing surveillance may affect patient outcomes. Finally, we focused on one surgical procedure in one state; the applicability of these findings to other procedures and other states is therefore limited. However, our study is strengthened by inclusion of survey data from 38 of the 46 hospitals that performed abdominal aortic surgery in Maryland.

Because complications are influenced by a complex array of factors, many of which may be unrelated to nursing, it could be debated whether we should link nurse staffing and complications as a measure of quality. Although work in this area is just beginning, our study and recently published studies support the idea that the level of nursing surveillance distinguishes hospitals with lower complication rates from those with higher complication rates.[4, 6]

Our results are important because they identify specific and potentially modifiable ICU characteristics that could be altered to reduce ICU complications and length of stay in high-risk surgical patients. Additional research is needed to further define the optimal ICU nurse-to-patient ratio for an ICU with a given severity of illness. When hospital administrators consider having ICU nurses care for more patients to reduce costs, they should consider the impact of this change on quality of care. In patients undergoing abdominal aortic surgery, more ICU nurses per patient during the day is associated with reduced risk for medical, particularly pulmonary, complications.

Take-Home Points

- **Although patients in intensive care units (ICUs) require substantial amounts of nursing care, ICU nurse staffing varies widely among hospitals.**
- **We examined the effect of having fewer ICU nurses (nurses providing care to three or four patients) versus more ICU nurses (nurses providing care for one or two patients) for patients undergoing abdominal aortic aneurysm repair in 39 Maryland hospitals.**
- **Although mortality did not differ between the two groups, patients in hospitals with fewer ICU nurses were more likely to have postoperative complications, particularly pulmonary insufficiency and reintubation.**
- **These differences persisted after adjusting for patient characteristics and for hospital and surgeon volume.**
- **Nurse staffing in the ICU affects the quality of postoperative care.**

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