Patient to Nurse Ratio and Risk of Ventilator-Associated Pneumonia in Critically Ill Patients

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Objective To determine how the patient to nurse ratio affects risk for ventilator-associated pneumonia.

Methods Data from an earlier study in 27 intensive care units in 9 European countries were examined in a secondary analysis. The initial cohort included 2585 consecutive patients who had mechanical ventilation (1) after admission for treatment of pneumonia or (2) for more than 48 hours irrespective of the diagnosis at admission. In units with variable staffing levels, the highest patient to nurse ratio in a 24-hour period was considered. Patients from 6 units that did not provide data on nurse staffing levels were excluded from the analysis.

Results Ventilator-associated pneumonia developed in 393 of the 1658 patients (23.7%) in the secondary cohort. In units with patient to nurse ratios of 1 to 1, 2 to 1, 2.5 to 1, and 3 to 1, rates were 9.3%, 25.7%, 18.7%, and 24.2%, respectively ($P = .003$). Rates were significantly lower ($P = .002$) in units with a ratio of 1 to 1 (9.3%) than in units with a ratio of more than 1 patient to 1 nurse (24.4%). After adjustments for confounding covariates, ratios of more than 1 patient to 1 nurse were no longer associated with increased risk for ventilator-associated pneumonia.

Conclusions A patient to nurse ratio of 1 to 1 appears to be associated with a lower risk for ventilator-associated pneumonia, but after adjustments for confounding covariates, the difference is not significant. (*American Journal of Critical Care.* 2011;20:e1-e9)

Ventilator-associated pneumonia (VAP) remains the most frequent nosocomial infection among intensive care unit (ICU) patients. The rate of VAP depends on the risk profile of the index patient population and the duration of mechanical ventilation (exposure time).[1,2] In a systematic review,[3] the estimated pooled cumulative incidence of VAP in patients receiving mechanical ventilation was 9.7% (95% confidence interval [CI], 7.0-12.5). The impact of VAP on morbidity and mortality is serious. In general, VAP prolongs the duration of a patient's ICU stay by 4 to 10 days and contributes to an increase in hospital costs that exceeds $10 000 per case.[4-6] Besides the substantial added cost, VAP heralds an important risk of death. Attributable mortality rates as assessed in matched cohort studies range from zero to a dramatic 50%.[7] These striking differences in fatality rates can be explained by differences in study methods (eg matching criteria), target population (eg, age, immune status), causative microorganisms and their antibiotic susceptibility patterns, and appropriateness of antimicrobial therapy.[8-13] Other issues that might affect outcome in VAP patients, such as the role of specific nursing protocols, the value of advanced nurse practitioners in the treatment of VAP, compliance with guidelines of the Surviving Sepsis Campaign, and so on, have not been studied extensively.

Because of the hazardous consequences of VAP, prevention of the disease has become a priority target in large-scale efforts in health care quality improvement.[14] Enhancement of knowledge of evidence-based recommendations to prevent VAP and multifaceted implementation of care bundles focused on measures to prevent VAP may reduce the risk for this pneumonia.[15-22] Yet, because of the high workload and degree of urgency needed in ICUs, proper compliance with recommendations is difficult. Furthermore, the shortage of qualified ICU nurses is a common problem in many European countries. Epidemiological cohort studies[23-26] clearly indicate that lower than average staffing levels are associated with poor quality of care, an increased risk of adverse events such as medication errors and needle-stick injuries, and noncompliance with hand hygiene recommendations. Thus, shortages of hospital resources, including suboptimal nurse staffing levels, may be a crucial element in the effort to minimize nosocomial infection rates. Our objective in this study was to assess relationships between nurse staffing levels (patient to nurse ratio) and the risk of VAP in patients treated with mechanical ventilation.

High workload and urgency in intensive care units makes compliance with ventilator-associated pneumonia recommendations difficult.

Methods

EU-VAP/CAP is a prospective, observational survey conducted in 27 ICUs in 9 European countries: Belgium, France, Germany, Greece, Italy, Ireland, Portugal, Spain, and Turkey. Organizational aspects of the study are described elsewhere.[27] All patients who were admitted to the ICU for treatment of pneumonia or received invasive mechanical ventilation

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for more than 48 hours, irrespective of the admission diagnosis, were included in the initial cohort.

Definitions and Data Collected

VAP was defined as (1) a pulmonary infection that occurred 48 hours or more after endotracheal intubation in patients with no evidence of pneumonia at the time of intubation or (2) the diagnosis of a new pulmonary infection if the initial admission to the ICU was for pneumonia.[28] Late-onset VAP was defined as VAP that occurred more than 5 days after intubation. Patient demographics, primary diagnosis, ICU and hospital lengths of stay, duration of mechanical ventilation, and ICU mortality were recorded for all patients. Days at risk for VAP were defined as the number of days of treatment with mechanical ventilation before the onset of VAP or, for patients in whom VAP did not develop, the total number of days of treatment with mechanical ventilation.

Underlying diseases were defined as in the primary article[27] on the EU-VAP study.

Severity of underlying disease was assessed by using the McCabe classification of comorbid conditions. In this classification system, patients' prognoses are roughly estimated and categorized into 3 main groups: likely to survive more than 5 years (nonfatal underlying disease), likely to survive 1 to 5 years (ultimately fatal), or likely to die within 1 year (rapidly fatal).

Severity of acute illness was assessed by using the Simplified Acute Physiology Score (SAPS) II,[29] a well-validated scoring system that has been used for years as a standard measure to quantify severity of acute illness. The SAPS II takes into account the type of admission (medical, scheduled or unscheduled surgery), chronic diseases (metastatic carcinoma, hematological malignant tumor), age, score on the Glasgow Coma Scale, hemodynamic and respiratory status, temperature, white blood cell count, urine output, liver tests, and electrolyte balance.

Data were recorded by the investigators at the individual study sites on paper-based case report forms. These forms were sent to the central study site where the data were put into an electronic database and checked for inconsistencies by the principal investigators.

The initial study cohort included 2585 patients. Because the focus of the study reported here was prevention of VAP, data on patients with a clinical diagnosis of community-acquired pneumonia, non–ventilator-associated hospital-acquired pneumonia, or very early VAP (due to aspiration and developing within 48 hours after intubation), were excluded from the analysis. Data on patients from 6 ICUs that did not provide data on nurse staffing levels were also excluded from the analysis. Hence, our study cohort consisted of 1658 patients who had mechanical ventilation for at least 48 hours.

Routine staffing levels for all available ICU beds were considered, irrespective of bed occupancy. Routine staffing level is defined as the patient to nurse ratio that is standard in a particular ICU. As such, unit-based standard nurse staffing levels were used irrespective of acute shortages of staff and number of patients present. Daily bed occupancy levels were not taken into account because this cohort consisted solely of patients who received mechanical ventilation. Hence, actual day-to-day patient to nurse ratios were not available for the analysis. For units with variable staffing levels (eg, 1 to 1 during day shifts and 2 to 1 during night shifts), the highest patient to nurse ratio in a 24-hour period was considered. In European countries, ICU nurses are generally qualified to manage ventilators. The use of respiratory therapists for ventilator management is rare.

The participating centers received ethical approval from the appropriate institutions. Informed consent was waived because the study was observational.

Statistical Analysis

Medians and interquartile ranges were used for continuous variables and numbers and percentages for discrete variables. For comparisons between groups, the Mann-Whitney test and the Fisher exact test or χ^2 test were used as appropriate. Independent relationships with development of VAP were assessed by using a logistic regression analysis. Variables considered in the logistic regression analysis either showed a moderate relationship ($P < .10$) in univariate analysis or a logic relationship with the dependent variable. Variables considered were age, SAPS II, underlying diseases, admission diagnosis, and patient to nurse ratio. A stepwise variable elimination was then performed to develop the final model. Variables with P greater than .15 were stepwise removed. The patient to nurse ratio was kept in the model irrespective of the associated P value. According to the reference category in patient to nurse ratio, 4 different logistic regression models were generated: model I with 4 staffing level ratios (1 to 1, 2 to 1, 2.5 to 1, and 3 to 1) and a 1 to 1 ratio

> Lower than average staffing levels are associated with poor quality of care.

> Routine intensive care unit staffing levels were used, irrespective of bed occupancy.

as the reference category; model II with 2 staffing level ratios (1 to 1 and >1 to 1) and a 1 to 1 ratio as the reference category; model III with 2 staffing level ratios (2 to 1 and >2 to 1) and a 2 to 1 ratio as the reference category; and model IV with 2 staffing level ratios (<3 to 1 and 3 to 1) and a less than 3 to 1 ratio as the reference category. Results of the regression analysis are reported as odds ratios (OR) and 95% CIs.

Results

VAP developed in 393 of the 1658 patients (23.7%) during their ICU stay; 220 of the patients with VAP had late-onset VAP (13.3%). The patient to nurse ratio was constantly 1 to 1 in only 1 ICU. In 10 ICUs, the highest patient to nurse ratio was 2 to 1; 4 units had a 2.5 to 1 ratio, and 6 had a 3 to 1 ratio. VAP rates in units with patient to nurse ratios of 1 to 1, 2 to 1, 2.5 to 1, and 3 to 1 were 9.3%, 25.7%, 18.7%, and 24.2%, respectively ($P = .003$; Table 1). Rates were significantly lower ($P = .002$) in units with a ratio of 1 to 1 (9.3%) than in units with a ratio of more than 1 patient to 1 nurse (24.4%).

However, important differences in patients' characteristics must also be considered (Table 1). Compared with other units, units with a ratio of more than 1 patient to 1 nurse had more patients admitted because of a medical condition or trauma and fewer patients admitted after elective surgery. Furthermore, duration of mechanical ventilation was significantly longer in the units with the ratio of more than 1 patient to 1 nurse (median, 8 vs 3 days; $P < .001$), as were the time at risk for VAP (median, 7 vs 3 days; $P < .001$), and the ICU stay (median, 12 vs 5 days; $P < .001$). On the other hand, severity of disease at the time of admission as indicated by the SAPS II was significantly higher among patients cared for in the unit with a 1 to 1 patient to nurse ratio than in the unit with more than 1 patient to 1 nurse (median, 53 vs 45; $P = .002$). After adjustments for such confounding covariates, a ratio of more than 1 patient to 1 nurse was no longer associated with increased risk for VAP (Table 2, models I and II).

Univariate analysis indicated no significant difference in VAP rates between patients cared for in ICUs with a patient to nurse ratio of 2 to 1 and those cared for in units with a ratio of more than 2 patients to 1 nurse (24.6% vs 22.1%; $P = .25$; Table 1). Also in multivariate analysis (Table 2), higher patient to nurse ratios, either more than 2 patients to 1 nurse or 3 patients to 1 nurse, were not associated with a higher risk for VAP (Table 2, models III and IV). In all logistic regression models, the following 3 variables

were identified as independent risk factors for the acquisition of VAP: the number of days at risk, admission because of trauma, and higher SAPS II. Results of the logistic regression models did not change when late-onset VAP was used as the dependent variable. With a patient to nurse ratio of 1 to 1 as the reference category, no other ratio was associated with risk for late-onset VAP (patient to nurse ratio 2 to 1: OR, 2.05; 95% CI, 0.62-6.69; patient to nurse ratio 2.5 to 1: OR, 1.68; 95% CI, 0.48-5.85; patient to nurse ratio 3 to 1: OR, 2.19; 95% CI, 0.66-7.32). In this regression model, the variable trauma (OR, 1.93; 95% CI, 1.35-2.73) and an increasing number of days at risk (OR, 1.06; 95% CI, 1.05-1.07) were the predominate risk factors for late-onset VAP.

<div style="color:#c0562e; font-size:larger;">No association between high staffing levels and reduced risk for ventilator-associated pneumonia was found.</div>

Discussion

In this study, based on a large cohort of patients from 21 European ICUs who were treated with mechanical ventilation, we found no association between high staffing levels (patient to nurse ratio <2 to 1) and reduced risk for VAP. Although a patient to nurse ratio of 1 to 1 was associated with a lower risk of VAP in univariate analysis, after adjustment for covariates, this observation was no longer significant. Factors such as admission because of trauma, number of days at risk, and disease severity seem to be stronger determinants of VAP.

Our observations differ from the results of Hugonnet et al,[30] who explored the relationship between staffing level and development of VAP in a single-center cohort of 2470 medical ICU patients in which the average patient to nurse ratio was 1.9 to 1. Multivariate Cox regression analysis indicated that higher staffing levels reduced the risk for late-onset VAP, although the reduction was borderline significant (adjusted hazard ratio, 0.42; 95% CI, 0.18 to 0.99) and was not evident in early-onset VAP (hazard ratio, 0.78; 95% CI, 0.42 to 1.45) or when all VAP cases were considered (hazard ratio, 0.66; 95% CI, 0.40 to 1.10). We focused on late-onset VAP and did not find a significant association between higher staffing levels and a reduced risk for late-onset VAP.

<div style="color:#c0562e; font-size:larger;">Higher intensive care unit nurse staffing levels are associated with better survival rates.</div>

Although data on the relationship between nurse staffing levels and VAP are scarce, more reports are

Table 1
Characteristics of patients receiving mechanical ventilation according to patient to nurse ratio

Characteristic[a]	Patient to nurse ratio				
	1:1	2:1	2.5:1	3:1	P
No. of patients	75	991	230	362	
No. of centers	1	10	4	6	
Patient to nurse ratio, median (25th-75th percentile)	1 (0)	2 (0)	2.21 (0.81)	2.26 (0.46)	<.001
Male sex	47 (63)	632 (64)	148 (64)	213 (59)	.30
Age, median (25th-75th percentile), y	58 (38-70)	59 (41-71)	69 (58-77)	69 (56-77)	<.001
McCabe classification					NA
No underlying disease	0 (0)	47 (5)	3 (1)	8 (2)	
Nonfatal	47 (63)	697 (70)	121 (53)	220 (61)	
Ultimately fatal	24 (32)	210 (21)	81 (35)	100 (28)	
Rapidly fatal	4 (5)	37 (4)	25 (11)	36 (10)	
SAPS II on ICU admission, median (25th-75th percentile)	53 (39-62)	42 (33-53)	44 (35-57)	49 (39-63)	<.001
Diagnostic category					<.001
Medical	35 (49)	533 (55)	160 (71)	276 (76)	
Surgical, elective	20 (28)	91 (10)	34 (16)	25 (7)	
Surgical, emergency	11 (15)	100 (11)	20 (9)	22 (6)	
Trauma	6 (8)	247 (25)	13 (6)	41 (11)	
Underlying conditions					
Chronic respiratory failure	3 (4)	40 (4)	18 (8)	29 (8)	.01
Chronic heart failure	9 (12)	70 (7)	36 (16)	48 (13)	<.001
Diabetes	5 (7)	30 (3)	21 (9)	23 (6)	<.001
Chronic obstructive pulmonary disease	1 (1)	54 (5)	31 (14)	22 (6)	NA
Cirrhosis	3 (4)	24 (2)	1 (<1)	8 (2)	.19
Malignant neoplasm[b]	3 (4)	40 (4)	13 (6)	20 (6)	NA
Immunodeficiency[c]	4 (5)	66 (7)	22 (10)	32 (9)	.28
Alcohol abuse	8 (11)	26 (3)	7 (3)	7 (2)	.001
Intravenous drug abuse	4 (5)	6 (1)	0 (0)	0 (0)	NA
Homelessness	2 (3)	0 (0)	0 (0)	2 (1)	NA
Mechanical ventilation, median (25th-75th percentile), d	3 (2-5)	8 (4-16)	7 (3-17)	8 (4-15)	<.001
Days at risk for VAP,[d] median (25th-75th percentile)	3 (2-4)	7 (4-15)	7 (3-16)	8 (4-15)	<.001
Time to onset of VAP,[e] median (25th-75th percentile), d	4 (3-6)	5 (3-9)	6 (3-12)	6 (3-10)	.003
VAP	7 (9.3)	255 (25.7)	43 (18.7)	88 (24.2)	.003
ICU stay, median (25th-75th percentile), d	5 (3-9)	13 (7-23)	11 (5-20)	11 (6-20)	<.001
Hospital stay, median (25th-75th percentile), d	23 (15-47)	22 (12-41)	18 (8-31)	17 (9-31)	<.001

Abbreviations: ICU, intensive care unit; NA, P value not applicable because 1 or more cells has an expected count less than 5; SAPS, Simplified Acute Physiology Score; VAP, ventilator-associated pneumonia.

[a] Values are number (%) of patients unless otherwise indicated. Because of rounding, percentages may not total 100.
[b] Patients with either solid tumor with or without metastatic spread or a hematologic malignant neoplasm.
[c] Patients with (1) congenital or acquired immunodeficiency syndrome, (2) malignant neoplasms treated with cytotoxic or immunosuppressive agents, or (3) prolonged glucocorticoid or immunosuppressive treatment.
[d] Days of mechanical ventilation until development of VAP; total duration of mechanical ventilation in patients in whom VAP did not develop.
[e] Only patients with VAP are considered.

Patient to nurse ratio			Patient to nurse ratio			Patient to nurse ratio		
1:1	>1:1	P	≤2:1	>2:1	P	<3:1	3:1	P
75	1583		1066	592		1296	362	
1	20		11	10		15	6	
1 (0)	2.1 (0.26)	<.001	19.9 (0.27)	2.24 (0.37)	<.001	1.98 (0.27)	2.26 (0.46)	<.001
47 (63)	993 (63)	.99	679 (64)	361 (61)	.21	827 (64)	213 (59)	.06
58 (38-70)	63 (47-74)	.08	59 (41-71)	69 (57-77)	<.001	62 (44-73)	69 (56-77)	<.001
		NA			<.001			.001
0	58 (4)		47 (4)	11 (2)		50 (4)	8 (2)	
47 (63)	1038 (66)		744 (70)	341 (58)		865 (67)	220 (61)	
24 (32)	391 (25)		234 (22)	181 (31)		315 (24)	100 (28)	
4 (5)	98 (6)		41 (4)	61 (10)		66 (5)	36 (10)	
								<.001
53 (39-62)	45 (35-56)	.002	43 (33-54)	47 (37-60)	<.001	44 (34-55)	49 (39-63)	
		<.001			<.001			<.001
35 (47)	969 (62)		568 (54)	436 (74)		611 (57)	270 (75)	
20 (28)	150 (10)		111 (11)	59 (10)		145 (12)	25 (7)	
11 (15)	142 (9)		111 (11)	42 (7)		131 (11)	22 (6)	
6 (8)	301 (19)		253 (24)	54 (9)		259 (21)	41 (12)	
3 (4)	87 (5)	.58	43 (4)	47 (8)	.001	61 (5)	29 (8)	.02
9 (12)	154 (10)	.52	79 (7)	84 (14)	<.001	115 (9)	48 (13)	.02
5 (7)	74 (5)	.43	35 (3)	44 (7)	<.001	56 (4)	23 (6)	.11
1 (1)	107 (7)	.06	55 (5)	53 (9)	.003	86 (7)	22 (6)	.69
3 (4)	33 (2)	.27	27 (3)	9 (2)	.17	28 (2)	8 (2)	.96
3 (4)	73 (5)	NA	43 (4)	33 (6)	.06	56 (4)	20 (6)	.41
4 (5)	120 (8)	NA	70 (7)	54 (9)	.06	92 (7)	32 (9)	.02
8 (11)	40 (3)	<.001	34 (3)	14 (2)	.33	41 (3)	7 (2)	.21
4 (5)	6 (<1)	NA	10 (1)	0 (0)	NA	10 (1)	0 (0)	NA
2 (3)	2 (<1)	NA	2 (<1)	2 (<1)	NA	2 (<1)	2 (<1)	NA
3 (2-5)	8 (4-16)	<.001	8 (4-15)	7 (4-15)	.68	7 (4-15)	8 (4-15)	.14
3 (2-4)	7 (4-15)	<.001	7 (4-14)	7 (4-15)	.27	7 (3-15)	8 (4-15)	.71
4 (3-6)	5 (3-9)	.004	5 (3-9)	6 (3-11)	.16	5 (3-9)	6 (3-10)	.26
7 (9.3)	386 (24.4)	.002	262 (24.6)	131 (22.1)	.25	305 (23.5)	88 (24.2)	.80
5 (3-9)	12 (6-22)	<.001	12 (6-22)	11 (6-20)	.36	12 (6-21)	11 (6-20)	.72
23 (15-47)	20 (11-36)	.02	22 (12-42)	17 (9-31)	<.001	21 (12-40)	17 (9-32)	<.001

Table 2
Risk factors for the acquisition of ventilator-associated pneumonia: results of a logistic regression analysis

Risk factor	Odds ratio	95% Confidence interval	P
Model I (n = 1658)			
Patient to nurse ratio			
1:1 (reference; n = 75)	–	–	–
2:1 (n = 991)	1.78	0.80 - 4.97	.16
2.5:1 (n = 230)	1.32	0.55 - 3.13	.54
3:1 (n = 362)	1.74	0.76 - 4.99	.19
Days at risk[a] (per day increase)	1.06	1.05 - 1.07	<.001
Trauma (n = 307)	2.12	1.59 - 2.83	<.001
SAPS II (per 10-point increase)	0.92	0.85 - 0.99	.04
Model II (n = 1658)			
Patient to nurse ratio			
1:1 (reference; n = 75)	–	–	–
>1:1 (n = 583)	1.71	0.77 - 3.80	.19
Days at risk[a] (per day increase)	1.06	1.05 - 1.07	<.001
Trauma (n = 307)	2.21	1.66 - 2.93	<.001
SAPS II (per 10-point increase)	0.92	0.86 - 0.99	.04
Model III (n = 1658)			
Patient to nurse ratio			
≤2:1 (reference; n = 1066)	–	–	–
>2:1 (n = 592)	0.91	0.70 - 1.18	.47
Days at risk[a] (per day increase)	1.06	1.05 - 1.07	<.001
Trauma (n = 307)	2.19	1.65 - 2.92	<.001
SAPS II (per 10-point increase)	0.92	0.86 - 0.99	.04
Model IV (n = 1658)			
Patient to nurse ratio			
<3:1 (reference; n = 1296)	–	–	–
3:1 (n = 362)	1.05	0.78 - 1.07	.73
Days at risk[a] (per day increase)	1.06	1.05 - 1.07	<.001
Trauma (n = 307)	2.25	1.69 - 2.98	<.001
SAPS II (per 10-point increase)	0.92	0.85 - 0.99	.03

Abbreviations: –, not measured; SAPS, Simplified Acute Physiology Score.

[a] Days of mechanical ventilation until onset of pneumonia; total duration of ventilation for patients in whom ventilator-associated pneumonia did not develop.

available on the relationship between staffing levels and hospital-acquired pneumonia. In a systematic review, Lang et al[31] examined the relationship between the hospital-wide risk for pneumonia and nurse staffing levels. Their analysis revealed mixed results. First, some investigators[32,33] reported a deleterious effect of lower staffing levels on pneumonia rates in both medical and surgical wards but not among patients who underwent invasive vascular procedures.[33] Second, Lichtig et al[34] found an inverse relationship between staffing level and the occurrence of pneumonia in hospitals in California but not in hospitals in New York. In a cohort of patients after esophagectomy, Amaravadi et al[35] found that the risk for several postoperative pulmonary and infectious complications and the use of resources increased when 1 ICU nurse provided care for more than 2

patients at night. Finally, in some studies,[36-38] the researchers found no link between staffing levels and risk for pneumonia. On the basis of their systematic review, Lang et al[31] consequently concluded that the existing evidence neither confirms nor rules out an inverse relationship between nurse staffing and pneumonia rates. A certain relationship probably exists, but the effect is rather discrete and is easily diminished when a patient has other, more powerful, risk factors, such as admission because of trauma and (severity of) underlying conditions.

Despite the lack of an obvious relationship with risk for infection, higher nurse staffing levels in ICUs have been associated with better survival rates. Cho et al[39] investigated the deleterious effect of lower nurse staffing levels in a large Korean study with 27 372 patients from 42 tertiary and 194 secondary hospitals. Compared with a ratio of 2 patients to 1 nurse, each 1-patient increase in the ratio was associated with a 9% increase in the odds of death (OR, 1.09; 95% CI, 1.04 to 1.14). Because Cho et al did not have data for a patient to nurse ratio of 1 to 1, they could not evaluate the eventual beneficial effect of this high (1:1) staffing. These data indicate that more favorable staffing levels are associated with better quality of care and hence better patient outcomes.

Several limitations of our study must be addressed. The study was a secondary analysis and thus was not specifically designed for the research question. Consequently, the study was hampered by several confounders. First, among the ICUs, a patient to nurse ratio of 1 to 1 was the standard in only a single unit. Therefore, the external validity can be questioned. In addition, important differences in patient characteristics existed between this particular ICU and units with a lower staffing level (>1 patient to 1 nurse). The ICU with the 1 to 1 ratio had more patients who had had elective surgery and fewer trauma patients than the other units did. In our study, as well as in previous reports,[2,40] trauma is well recognized as a major and independent risk factor for VAP.

Furthermore, patients cared for in ICUs with a patient to nurse ratio of 1 to 1 experienced fewer days on the ventilator and thus fewer days at risk for VAP. A possible explanation is that the shorter period of ventilation dependency is a direct consequence of the 1 to 1 staffing level with a more proactive weaning strategy,[41] a situation that may reduce the risk of exposure to time-dependent complications such as nosocomial infections. However, we think that the shorter period of dependency is due to the preponderance of elective surgery patients. Compared with medical or trauma patients, patients

who have elective surgery most likely have a less troublesome weaning. Anyhow, after adjustment for the most important risk factors—ICU admission because of trauma, days at risk, and disease severity—higher staffing levels were not associated with a reduced risk for VAP in our cohort of patients.

Another limitation of our study is that the patient to nurse ratios we used were not the actual ratios as calculated on a daily basis (number of patients/number of nurses present per day). We used unit-based standard nurse staffing levels irrespective of acute staff shortages (eg, due to sick leave) and number of patients present. Hence, actual day-to-day patient to nurse ratios were not available for the analysis. A further limitation is that quality of care is not fully reflected by degree of staffing. Quality of care at the level of individual patients strongly depends on nurses' competencies. Recently, we discovered substantial shortages in the average knowledge level of European ICU nurses about evidence- based guidelines for VAP prevention,[42,43] and in addition, implementation of such recommendations is problematic.[44] Obviously, the database we used did not allow us to adjust for either knowledge and /or implementation level of best-practice recommendations. Finally, we have no knowledge of the compliance of distinct ICUs with evidence-based guidelines for the prevention of VAP, such as drainage of subglottic secretions, semi-recumbent positioning, and chlorhexidine-based oral care.

Conclusion

In this cohort of patients treated with mechanical ventilation, a patient to nurse ratio of 1 to 1 appeared to be associated with a lower risk for VAP. After adjustment for confounding covariates, however, the difference was no longer significant. Although higher staffing levels may be beneficial for other outcomes, the effect of trauma, general disease severity, and duration of mechanical ventilation are more important risk factors for VAP. Our data indicate that efforts to reduce the number of days at risk should be a priority in the prevention of VAP. Thus, our results underscore the value of a proactive extubation policy with a "sedation vacation" as recommended in current guidelines.[15] Further research is necessary to evaluate the relationship between higher staffing levels (patient to nurse ratio <2 to 1) and compliance rates with distinct evidence-based strategies to prevent VAP. In our study, the actual patient to nurse ratio should be taken into account (actual number of patients per nurse each day).

REFERENCES
1. Cook DJ, Walter SD, Cook RJ, et al. Incidence of and risk factors for ventilator-associated pneumonia in critically ill patients. *Ann Intern Med.* 1998;129(6):433-440.
2. Myny D, Depuydt P, Colardyn F, Blot S. Ventilator-associated pneumonia in a tertiary care ICU: analysis of risk factors for acquisition and mortality. *Acta Clin Belg.* 2005;60(3):114-121.
3. Safdar N, Dezfulian C, Collard HR, Saint S. Clinical and economic consequences of ventilator-associated pneumonia: a systematic review. *Crit Care Med.* 2005;33(10):2184-2193.
4. Papazian L, Bregeon F, Thirion X, et al. Effect of ventilator-associated pneumonia on mortality and morbidity. *Am J Respir Crit Care Med.* 1996;154(1):91-97.
5. Rello J, Ollendorf DA, Oster G, et al; VAP Outcomes Scientific Advisory Group. Epidemiology and outcomes of ventilator-associated pneumonia in a large US database. *Chest.* 2002;122(6):2115-2121.
6. Warren DK, Shukla SJ, Olsen MA, et al. Outcome and

attributable cost of ventilator-associated pneumonia among intensive care unit patients in a suburban medical center. *Crit Care Med.* 2003;31(5):1312-1317.

7. Chastre J, Fagon JY. Ventilator-associated pneumonia. *Am J Respir Crit Care Med.* 2002;165(7):867-903.

8. Agbaht K, Diaz E, Muñoz E, et al. Bacteremia in patients with ventilator-associated pneumonia is associated with increased mortality: a study comparing bacteremic vs non-bacteremic ventilator-associated pneumonia. *Crit Care Med.* 2007;35(9):2064-2070.

9. Blot S. Limiting the attributable mortality of nosocomial infection and multidrug resistance in intensive care units. *Clin Microbiol Infect.* 2008;14(1):5-13.

10. Blot S, Depuydt P, Vandewoude K, De Bacquer D. Measuring the impact of multidrug resistance in nosocomial infection. *Curr Opin Infect Dis.* 2007;20(4):391-396.

11. Depuydt P, Benoit D, Vogelaers D, et al. Systematic surveillance cultures as a tool to predict involvement of multidrug antibiotic resistant bacteria in ventilator-associated pneumonia. *Intensive Care Med.* 2008;34(4):675-682.

12. Depuydt PO, Vandijck DM, Bekaert MA, et al. Determinants and impact of multidrug antibiotic resistance in pathogens causing ventilator-associated-pneumonia. *Crit Care.* 2008; 12(6):R142. http://ccforum.com/content/pdf/cc7119.pdf. Accessed October 9, 2010.

13. Rello J, Sole-Violan J, Sa-Borges M, et al. Pneumonia caused by oxacillin-resistant Staphylococcus aureus treated with glycopeptides. *Crit Care Med.* 2005;33(9):1983-1987.

14. Berwick DM, Calkins DR, McCannon CJ, Hackbarth AD. The 100,000 Lives Campaign: setting a goal and a deadline for improving health care quality. *JAMA.* 2006;295(3):324-327.

15. Lorente L, Blot S, Rello J. Evidence on measures for the prevention of ventilator-associated pneumonia. *Eur Respir J.* 2007;30(6):1193-1207.

16. Bloos F, Müller S, Harz A, et al. Effects of staff training on the care of mechanically ventilated patients: a prospective cohort study. *Br J Anaesth.* 2009;103(2):232-237.

17. Marra AR, Cal RG, Silva CV, et al. Successful prevention of ventilator-associated pneumonia in an intensive care setting. *Am J Infect Control.* 2009;37(8):619-625.

18. O'Keefe-McCarthy S, Santiago C, Lau G. Ventilator-associated pneumonia bundled strategies: an evidence-based practice. *Worldviews Evid Based Nurs.* 2008;5(4):193-204.

19. Zilberberg MD, Shorr AF, Kollef MH. Implementing quality improvements in the intensive care unit: ventilator bundle as an example. *Crit Care Med.* 2009;37(1):305-309.

20. Blot SI, Labeau S, Vandijck D, Van Aken P, Claes B; Executive Board of the Flemish Society for Critical Care Nurses. Evidence-based guidelines for the prevention of ventilator-associated pneumonia: results of a knowledge test among intensive care nurses. *Intensive Care Med.* 2007;33(8): 1463-1467.

21. El-Khatib MF, Zeineldine S, Ayoub C, Husari A, Bou-Khalil PK. Critical care clinicians' knowledge of evidence-based guidelines for preventing ventilator-associated pneumonia. *Am J Crit Care.* 2010;19(3):272-276.

22. Lorente L, Blot S, Rello J. New issues and controversies in the prevention of ventilator-associated pneumonia. *Am J Respir Crit Care Med.* 2010;182(7):870-876.

23. Aiken LH, Clarke SP, Sloane DM. Hospital staffing, organization, and quality of care: cross-national findings. *Int J Qual Health Care.* 2002;14(1):5-13.

24. Clarke SP, Sloane DM, Aiken LH. Effects of hospital staffing and organizational climate on needlestick injuries to nurses. *Am J Public Health.* 2002;92(7):1115-1119.

25. Valentin A, Capuzzo M, Guidet B, et al; Research Group on Quality Improvement of the European Society of Intensive Care Medicine (ESICM); Sentinel Events Evaluation (SEE) Study Investigators. Errors in administration of parenteral drugs in intensive care units: multinational prospective study. *BMJ.* 2009;338:b814.

26. De Wandel D, Maes L, Labeau S, Vereecken C, Blot S. Behavioral determinants of hand hygiene compliance in intensive care units. *Am J Crit Care.* 2010;19(3):230-239.

27. Koulenti D, Lisboa T, Brun-Buisson C, et al; EU-VAP/CAP study group. Spectrum of practice in the diagnosis of nosocomial pneumonia in patients requiring mechanical ventilation in European intensive care units. *Crit Care Med.* 2009;37(8):2360-2368.

28. American Thoracic Society; Infectious Diseases Society of America. Guidelines for the management of adults with hospital-acquired, ventilator-associated, and healthcare-associated pneumonia. *Am J Respir Crit Care Med.* 2005; 171(4):388-416.

29. Le Gall JR, Lemeshow S, Saulnier F. A new Simplified Acute Physiology Score (SAPS II) based on a European/ North American multicenter study. *JAMA.* 1993;270(24):2957-2963.

30. Hugonnet S, Uçkay I, Pittet D. Staffing level: a determinant of late-onset ventilator-associated pneumonia. *Crit Care.* 2007;11(4):R80. http://ccforum.com/content/pdf/cc5974.pdf. Accessed October 9, 2010.

31. Lang TA, Hodge M, Olson V, Romano PS, Kravitz RL. Nurse-patient ratios: a systematic review on the effects of nurse staffing on patient, nurse employee, and hospital outcomes. *J Nurs Adm.* 2004;34(7-8):326-337.

32. Needleman J, Buerhaus P, Mattke S, Stewart M, Zelevinsky K. Nurse-staffing levels and the quality of care in hospitals. *N Engl J Med.* 2002;346(22):1715-1722.

33. Kovner C, Gergen PJ. Nurse staffing levels and adverse events following surgery in US hospitals. *Image J Nurs Sch.* 1998;30(4):315-321.

34. Lichtig LK, Knauf RA, Milholland DK. Some impacts of nursing on acute care hospital outcomes. *J Nurs Adm.* 1999;29(2):25-33.

35. Amaravadi RK, Dimick JB, Pronovost PJ, Lipsett PA. ICU nurse-to-patient ratio is associated with complications and resource use after esophagectomy. *Intensive Care Med.* 2000;26(12):1857-1862.

36. Cho SH, Ketefian S, Barkauskas VH, Smith DG. The effects of nurse staffing on adverse events, morbidity, mortality, and medical costs. *Nurs Res.* 2003;52(2):71-79.

37. Kovner C, Jones C, Zhan C, Gergen PJ, Basu J. Nurse staffing and postsurgical adverse events: an analysis of administrative data from a sample of US hospitals, 1990-1996. *Health Serv Res.* 2002;37(3):611-629.

38. Unruh L. Licensed nurse staffing and adverse events in hospitals. *Med Care.* 2003;41(1):142-152.

39. Cho SH, Hwang JH, Kim J. Nurse staffing and patient mortality in intensive care units. *Nurs Res.* 2008;57(5):322-330.

40. Hyllienmark P, Gårdlund B, Persson JO, Ekdahl K. Nosocomial pneumonia in the ICU: a prospective cohort study. *Scand J Infect Dis.* 2007;39(8):676-682.

41. Kress JP, Pohlman AS, O'Connor MF, Hall JB. Daily interruption of sedative infusions in critically ill patients undergoing mechanical ventilation. *N Engl J Med.* 2000;342(20):1471-1477.

42. Labeau S, Vandijck D, Rello J, et al. Evidence-based guidelines for the prevention of ventilator-associated pneumonia: results of a knowledge test among European intensive care nurses. *J Hosp Infect.* 2008;70(2):180-185.

43. Labeau S, Vandijck DM, Claes B, et al. Critical care nurses' knowledge of evidence-based guidelines for preventing ventilator-associated pneumonia: an evaluation questionnaire. *Am J Crit Care.* 2007;16(4):371-377.

44. Ricart M, Lorente C, Diaz E, Kollef MH, Rello J. Nursing adherence with evidence-based guidelines for preventing ventilator-associated pneumonia. *Crit Care Med.* 2003; 31(11):2693-2696.