MAJOR ARTICLE

Toward Improved Surveillance: The Impact of Ventilator-Associated Complications on Length of Stay and Antibiotic Use in Patients in Intensive Care Units

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Background. Hospitals and quality improvement agencies are vigorously focusing on reducing rates of hospital-acquired infection. Ventilator-associated pneumonia (VAP) is notoriously difficult to diagnose and surveillance is thwarted by the subjectivity of many components of the surveillance definition. Alternative surveillance strategies are needed. Ventilator-associated complications (VAC) is a simple, objective measure of respiratory deterioration.

Methods. VAC is defined by increases in fraction of inspired oxygen (FiO_2) by ≥15% or positive end-expiratory pressure (PEEP) by ≥2.5 cm H_2O lasting ≥2 days after stable or decreasing FiO_2 or PEEP lasting ≥2 days. We retrospectively assessed patients on mechanical ventilation for ≥48 hours in our study intensive care unit (ICU) using electronic medical record data. We analyzed the association between VAC and clinical diagnoses, ICU length of stay, duration of mechanical ventilation, antibiotic use, and mortality.

Results. We assessed 153 patients with VAC and 390 without VAC. VAC events were associated with significantly increased ICU length of stay, duration of mechanical ventilation, and consumption of broad-spectrum antibiotics but not with longer hospital stays or ICU mortality.

Conclusions. Surveillance for VAP is subjective and labor intensive. VAC is an objective measure which can be readily obtained from electronic records. It is associated with adverse outcomes and increased broad-spectrum antibiotic usage. VAC may be a useful surveillance tool. The utility of VAC prevention bundles merits assessment.

Keywords. ventilator-associated complication; ventilator-associated pneumonia; surveillance; intensive care unit; hospital-acquired infection.

Mechanically ventilated patients are at risk for many preventable complications including ventilator-associated pneumonia (VAP), fluid overload, pulmonary embolism, pneumothorax, and atelectasis. To date, though, only VAP is commonly used as a quality indicator for mechanically ventilated patients. VAP surveillance for internal quality assessment and external benchmarking is typically conducted using the National Healthcare Safety Network (NHSN) surveillance definitions published by the Centers for Disease Control and Prevention (CDC) [1–5].

VAP surveillance, however, has several shortcomings. First, the NHSN/CDC definitions (Table 1) are complex and time consuming to apply. Second, the definitions include many subjective components such

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Table 1. Surveillance Definition for Ventilator-Associated Pneumonia of the National Healthcare Safety Network and Centers for Disease Control and Prevention

Radiology	Two or more serial chest radiographs with at least 1 of the following: 1. New or progressive and persistent infiltrate 2. Consolidation 3. Cavitation
Systemic signs (at least 1)	1. Fever (>38°C or >100.4°F) 2. Leukopenia (<4000 WBC/μL) or leukocytosis (≥12 000 WBC/μL) 3. For adults ≥70 years old, altered mental status with no other recognized cause
Pulmonary signs (at least 2)	1. New onset of purulent sputum, or change in character of sputum, or increased respiratory secretions, or increased suctioning requirements 2. Worsening gas exchange (eg, desaturations, increased oxygen requirements, or increased ventilator demand) 3. New onset or worsening cough, or dyspnea, or tachypnea 4. Rales or bronchial breath sounds

Abbreviation: WBC, white blood cell.

as chest radiography, respiratory secretion assessment, and chest auscultation findings [6]. As a consequence, interobserver discordance for detecting VAP is high [7]. Third, the correlation between VAP defined using NHSN/CDC criteria and histological pneumonia is likely poor given that clinical signs have low specificity for VAP [8]. A streamlined surveillance definition for VAP (Table 2) was recently published [9], but the streamlined definition uses similar clinical criteria to the conventional definition and therefore is likely equally prone to mislabel VAP.

Many hospitals in the United States are now reporting "zero" VAP rates [10]. From the standpoint of intensive care providers, the elimination of VAP seems unrealistic even with state-of-the-art practice. It is noteworthy that >80% of references found in a PubMed search using the term "ventilator-associated tracheobronchitis" have been published since 2008 [11]. Some experts are now advocating abandoning VAP surveillance altogether [12].

Given the limited capacity to accurately identify VAP using clinical criteria, it might make more sense to focus surveillance on ventilator-associated complications in general rather than VAP specifically [9]. Focusing surveillance on ventilator-associated complications rather than VAP could help identify more patients with impaired outcomes, simplify surveillance, and eliminate the gamesmanship that subjective surveillance definitions permit [13].

Klompas and colleagues have proposed a simple, objective surveillance definition for ventilator-associated complications (VAC) [14]. They defined VAC as a sustained increase in ventilator settings after a period of stable or decreasing ventilator support. Subjective measures such as radiographic interpretations are not part of this definition. In a preliminary study comparing VAC versus VAP surveillance, both VAC and VAP predicted prolonged mechanical ventilation and intensive care unit (ICU) stay but only VAC was associated with increased hospital mortality [14]. Notably, VAC events are amenable to automated detection in ICUs with electronic medical records that include ventilator setting data.

Considering the drawbacks of VAP surveillance and the potential advantages of VAC surveillance, we elected to evaluate the association between VAC and patients' diagnoses and outcomes in a population of mechanically ventilated patients.

METHODS

We performed a retrospective study at the Department of Intensive Care Medicine, Royal Brisbane and Women's Hospital (Brisbane, Australia), a university-based, tertiary referral, adult multidisciplinary (medical and surgical) ICU with 30 beds. The unit has >2000 admissions per year, each with an average length of stay of 4 days.

Data were available from the database of the ICU's electronic medical records. All intensive care medical records had been electronic since 1996, initially with Carevue and since 2009 with Intellivue Clinical Information Portfolio (both Phillips, Eindhoven, Netherlands). The study institution has twice-weekly rounds by infectious disease physicians and clinical microbiologists and on-demand consultation access to infectious disease physicians.

We included all patients aged >18 years admitted to the study institution between 31 May 2009 and 12 January 2011 who were on mechanical ventilation for >48 hours. Patients who met inclusion criteria multiple times in multiple ICU stays were regarded as different patients. Patients requiring progressive increases in fraction of inspired oxygen (FiO2) or positive end-expiratory pressure (PEEP) from intubation without subsequent stabilization were also excluded, as the disease precipitating intubation more likely contributed to these phenomena rather than pulmonary complications secondary to mechanical ventilation. Patients on high-frequency oscillatory ventilation were excluded. Extracorporeal membrane oxygenation was not available at the study institution. Patient data including daily minimum PEEP and daily minimum FiO_2 were obtained from the electronic patient database. Noninvasive positive pressure ventilation was not defined as mechanical ventilation. We reviewed the medical records of patients with VAC from 1 day before to 1 day after

Table 2. Streamlined Definition for Ventilator-Associated Pneumonia[a]

Radiology	Two or more serial chest radiographs with at least 1 of the following: 1. New or progressive and persistent infiltrate 2. Consolidation 3. Cavitation
Systemic signs	1. Fever (>38°C or >100.4°F) OR 2. Leukopenia (<4000 WBC/μL) or leukocytosis (≥12 000 WBC/μL)
Pulmonary signs	1. ≥25 neutrophils per low-power field on Gram stain of endotracheal aspirate or bronchoalveolar lavage specimen AND 2. ≥2 d of stable or decreasing daily minimum PEEP followed by a rise in daily minimum PEEP of ≥2.5 cm H_2O, sustained for ≥2 calendar days; or ≥2 d of stable or decreasing daily minimum FiO_2 followed by a rise in daily minimum FiO_2 of ≥0.15 points, sustained for ≥2 calendar days

Abbreviations: FiO_2, fraction of inspired oxygen; PEEP, positive end-expiratory pressure; WBC, white blood cell.

[a]Source: Klompas et al [9].

VAC onset to identify clinical diagnoses potentially associated with VAC.

The primary outcome was hospital mortality and the secondary outcomes were ICU mortality, duration of mechanical ventilation, ICU length of stay, and hospital length of stay. We also assessed broad-spectrum antibiotic usage, focusing on agents typically prescribed for VAP at this institution (eg, piperacillin/tazobactam, meropenem, ciprofloxacin, and vancomycin), defined in both grams per patient and defined daily dose (DDD) per 100 patient-days in accordance with the World Health Organization Collaborating Centre for Drug Statistics and Methodology [15].

VAC was defined as "≥2 days of stable or decreasing daily minimum PEEP or FiO_2 followed by a rise in daily minimum PEEP by ≥2.5 cm H_2O lasting ≥2 days or a rise in daily minimum FiO_2 by ≥15% lasting ≥2 days" [14]. If patients were reintubated within 48 hours of extubation, the total time of mechanical ventilation was considered continuous. The unit clinical guideline was for low tidal volume ventilation and broadly consistent with the Acute Respiratory Management in ARDS (ARMA) trial protocol for the setting of FiO_2 and PEEP [16].

Study approval was provided by the Institutional Review Board of the Royal Brisbane and Women's Hospital.

We did a power calculation using results from a prior investigation [11]. We assumed a hospital mortality rate in controls (patients without VAC) of 23% and an odds ratio of death for cases (patients with VAC) of 2.0 [14]. To achieve 80% power and 5% level of significance, 110 cases and 440 controls were required (assuming Fisher exact test for independent groups in a retrospective study). SAS software version 9.2 for Windows (SAS Institute, Cary, North Carolina) was used for statistical analysis. We compared potential confounding variables between patients with and without VAC using Wilcoxon 2-sample tests and χ^2 tests. All outcomes compared were time to event outcomes and analyzed by Cox regression. A positive VAC was included as a time-dependent variable in the analysis to avoid time-dependent bias [17]. Patients not having the outcome of interest were censored at the time they were no longer at risk of that event or at study end on 10 May 2011. Robust sandwich covariance matrix estimates were used to account for the 11 patients who were included twice on separate occasions. Survival curves were plotted based on the method of Simon and Makuch for time-dependent binary covariates [18]. In the case of days in ICU, 2 curves were plotted, one representing the probability of remaining in the ICU beyond time t conditional on having VAC by time x, the other one representing the probability of remaining in the ICU beyond time t conditional on not having VAC by time x. The calculations assume presence in the ICU at time x. We chose $x = 3$ days as this was the earliest a patient was discharged from the ICU (hence all patients are included) and 40% of patients having VAC had had it by this time. Similarly, for days on mechanical ventilator, we chose $x = 2$ days as this was the earliest a patient was taken off the ventilator and a third of patients having VAC had had it by this time.

RESULTS

During the study period, 3844 patients were admitted and 1657 received mechanical ventilation. Of these, 577 were ventilated for >48 hours. Of the 577, 34 were excluded: 9 received high-frequency oscillatory ventilation and 25 experienced progressive respiratory deterioration resulting in death without stabilization of FiO_2 or PEEP. Data from the remaining 543 patients were analyzed. These included 11 patients admitted twice during the study period.

A total of 153 patients had VAC (28%), including 4 patients who were counted twice owing to multiple admissions. Patient characteristics are shown in Table 3. Patients with VAC were more likely to have chronic obstructive pulmonary disease and renal insufficiency but less likely to have cerebrovascular disease (Table 3). There was no association between VAC and age, sex, or severity of illness score at onset of ICU admission.

Patient outcomes are summarized in Table 4. The mean and median days from the initiation of mechanical ventilation to the onset of VAC were 5.8 (SD, 5.8) and 4.3, respectively, for the 153 patients with VAC.

Table 3. Comparison of Potential Confounding Variables Between Patients With or Without Ventilator-Associated Complications

Variable	Patients With VAC (n = 153)	Patients Without VAC (n = 390)	*P* Value
Age, y, mean (SD)	53 (17)	52 (18)	.59
APACHE II score, mean (SD)	22 (7)	21 (7)	.51
Sex, No. female/No. male (% female)	61/153 (39.7)	150/390 (38.5)	.76
Diagnostic categories[a]			.071
Comorbidities			.007
Ischemic heart disease	19 (12.4)	46 (11.8)	.88
Congestive heart failure	11 (7.2)	12 (3.1)	.055
Cerebrovascular disease	30 (19.6)	120 (30.8)	.01
COPD	44 (28.8)	60 (15.4)	.001
Sleep apnea	6 (3.9)	8 (2.1)	.23
Collagen disease	8 (5.2)	12 (3.1)	.31
Chronic liver disease	16 (10.5)	24 (6.2)	.1
Diabetes mellitus	28 (18.3)	50 (12.8)	.11
Acute kidney injury	55 (35.9)	82 (21.0)	<.001
Chronic renal failure	9 (5.9)	27 (6.9)	.85
Malignancy	26 (17.0)	47 (12.1)	.16

Data are No. (%) unless otherwise specified. On the basis of these results, cerebrovascular disease, chronic obstructive pulmonary disease, and acute kidney injury are all potential confounding variables for the association between ventilator-associated complications status and outcomes of interest.

Abbreviations: APACHE II, Acute Physiology and Chronic Health Evaluation II; COPD, chronic obstructive pulmonary disease; SD, standard deviation; VAC, ventilator-associated complications.

[a]Diagnostic categories were classified on the basis of the Australia and New Zealand Intensive Care Society (ANZICS) Adult Patient Database AORTIC Manual, version 4.0, and their distributions were similar between the 2 groups.

The hazard ratios for time-to-event outcomes are summarized in Table 5, with survival curves for days to ICU discharge and days of mechanical ventilation in Figures 1 and 2, respectively. VAC was associated with prolonged duration of mechanical ventilation and ICU length of stay. VAC decreased the probability of ICU discharge by 48% and weaning from mechanical ventilation by 30% on average over the follow-up period. There was no association between VAC and days to hospital death (hazard ratio [HR], 0.88; 95% confidence interval [CI], .57–1.35; $P = .55$), days to ICU death (HR, 1.25; 95% CI, .69–2.28; $P = .46$), or days to hospital discharge (HR, 0.77; 95% CI, .54–1.11; $P = .16$). Stratifying outcomes by potential confounding variables provided similar results (Table 5).

Of the 153 patients with VAC, 47 (30.7%) had positive microbiological results from respiratory samples (ie, bacteria with quantity of >2 positive in semiquantitative endotracheal aspirate culture or $\geq 10^5$ colony forming units per milliliter in

Table 4. Descriptive Statistics on Outcomes by Ventilator-Associated Complication Status

Outcomes	Patients With VAC	Patients Without VAC
Days to VAC from ICU admission	6 (6), 4 (n = 153)	NA
ICU length of stay, d	22 (25), 16 (n = 153)	11 (7), 10 (n = 390)
Hospital length of stay, d	57 (58), 40 (n = 138)	38 (35), 28 (n = 362)
Duration of mechanical ventilation, d	17 (20), 11 (n = 153)	6.2 (5.0), 4.1 (n = 390)
ICU death	17/153 (11.1%)	39/390 (10.0%)
Hospital death	28/138 (20.3%)	102/362 (28.2%)

Data are mean (standard deviation), median, unless otherwise specified. Please note that these data are descriptive only and formal comparison of the groups is not appropriate because of the time-dependent nature of ventilator-associated complications status.

Abbreviations: ICU, intensive care unit; NA, not applicable; VAC, ventilator-associated complications.

Table 5. Comparison of Univariate Time-to-Event Outcomes Between Patients With and Those Without Ventilator-Associated Complications

Outcome	Hazard Ratio	95% Confidence Interval	*P* Value
Days to ICU death	1.25	.70–2.24	.46
Stratified by confounders[a]	1.40	.77–2.54	.27
Days to hospital death	0.88	.57–1.36	.56
Stratified by confounders[a]	0.90	.58–1.40	.65
Days to ICU discharge	0.52	.43–.62	<.0001
Stratified by confounders[a]	0.51	.42–.62	<.0001
Days to hospital discharge	0.77	.53–1.13	.18
Days of mechanical ventilation	0.70	.59–.83	<.0001
Stratified by confounders[a]	0.74	.62–.89	.001

The univariate results suggested that having a ventilator-associated complications (VAC) event was associated with a 48% decreased hazard of intensive care unit discharge and a 30% decreased hazard of being taken off mechanical ventilation. There were no differences between the groups for mortality and days to hospital discharge. However, 95% confidence intervals were so wide that the possibility of clinically significant differences in these outcomes due to VAC events could not be ruled out.

Abbreviations: ICU, intensive care unit; VAC, ventilator-associated complications.

[a] Confounding variables were any of those associated with VAC status (ie, cerebrovascular disease, acute kidney injury, and chronic obstructive pulmonary disease) that were also associated with the outcome of interest ($P < .05$). There were no confounders found for days to hospital discharge.

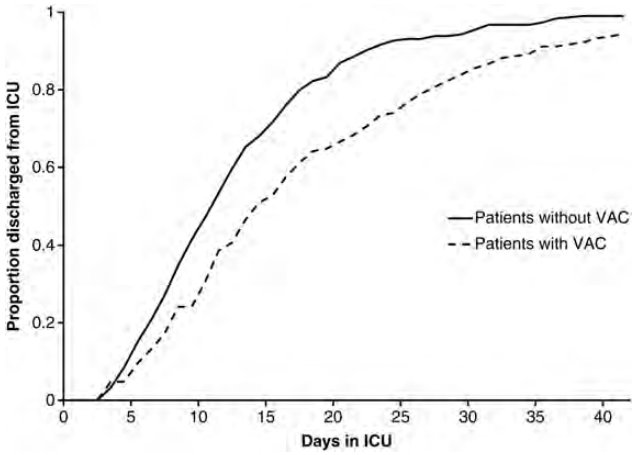

Figure 1. Days in the intensive care unit (ICU) by ventilator-associated complications (VAC) status. This survival curve shows that having a VAC event is associated with longer lengths of stay in the ICU. The median length of stay in ICU for patients without VAC is 11 days compared with 14 days for patients with VAC, but the difference is greater at the 90th percentile (21 days for patients without VAC vs 35 days for patients with VAC). Abbreviations: ICU, intensive care unit; VAC, ventilator-associated complications.

bronchoalveolar lavage) within 1 day before or after the occurrence of VAC event. Organisms included methicillin-susceptible *Staphylococcus aureus* (n = 11 [23.4%]), *Haemophilus influenzae* (n = 11 [23.4%]), *Pseudomonas aeruginosa* (n = 9 [19.1%]), *Serratia marcescens* (n = 4 [8.5%]), *Klebsiella pneumoniae* (n = 4 [8.5%]), *Stenotrophomonas maltophilia* (n = 3 [6.4%]), and others (n = 3 [6.4%]). Of the 47 VAC with positive respiratory cultures, antibiotics were initiated in 40 within 1 day before or after VAC onset. Medical record review confirmed physician intention to treat VAP. Interestingly, 7 of the 47 VAC with positive cultures were also treated for acute pulmonary edema with furosemide (including 5 of the patients started on antibiotics for VAP).

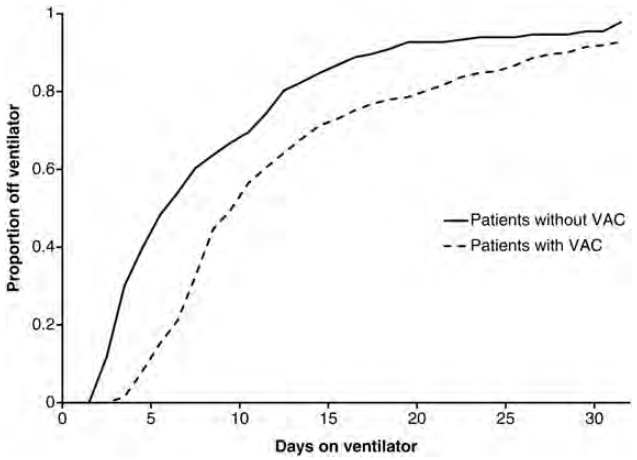

Figure 2. Days on mechanical ventilator by ventilator-associated complications (VAC) status. This survival curve shows that having a VAC event is associated with longer duration of mechanical ventilation in the intensive care unit. The median duration of mechanical ventilation for patients without VAC is 5 days compared with 9 days for patients with VAC, but the difference is greater at the 90th percentile (16 days for patients without VAC vs 27 days for patients with VAC). Abbreviation: VAC, ventilator-associated complications.

Other etiologies that potentially explained VAC events based on medical record review were atelectasis (n = 25 [16.3%]), acute pulmonary edema (n = 18 [11.8%]), acute respiratory distress syndrome (n = 10 [6.5%]), pleural effusion (n = 5 [3%]), pulmonary embolism (n = 3 [2.0%]), aspiration (n = 3 [2.0%]), and abdominal distension (n = 2 [1.3%]). However, in 47 cases (31%), no particular cause explaining the VAC events was determined, although some of those patients appeared to be treated for VAP and/or fluid overload with antibiotics (n = 23) and/or furosemide (n = 17), including 10 patients who received both antibiotics and furosemide within 1 day before or after the onset of VAC events.

VAC patients received greater amounts of fluid and greater amounts of furosemide than patients without VAC over the course of their entire ICU stays. The mean and median maximum fluid balances during ICU stay were 14.9 L (SD, 14.7) and 10.8 L, respectively, for the patients with VAC and 7.4 L (SD, 6.1) and 7.4 L, respectively, for patients without VAC. The mean and median total furosemide doses during ICU stay were 432 mg (SD, 512) and 289 mg, respectively, for patients with VAC and 154 mg (SD, 254) and 40.0 mg, respectively, for patients without VAC.

VAC patients were administered 1.9 times more meropenem and 2.2 times more ciprofloxacin in DDD per 100 patient-days compared with non-VAC patients over the entire ICU stay (Table 6). Consumption of piperacillin/tazobactam and vancomycin in DDD per 100 patient-days was similar for the 2 groups (Table 6). On a grams per patient basis, VAC patients were given more piperacillin/tazobactam and meropenem compared with non-VAC patients but similar amounts of ciprofloxacin and vancomycin (Table 6). Antipseudomonal cephalosporins were rarely prescribed at the study institution. Intensive care specialists prescribed all antibiotics.

DISCUSSION

Patients with VAC in our study spent more time on mechanical ventilation, more days in intensive care, and consumed more broad-spectrum antibiotics compared to patients without VAC. VAC is a simple, objective, and electronically obtainable index that robustly predicts adverse outcomes in ventilated patients. VAC's objectivity, simplicity, association with poor outcomes, and potential for automation make it a

Table 6. Consumption of Selected Antibiotics During the Stay in Intensive Care Unit by Ventilator-Associated Complication Status

Antibiotic	Patients With VAC	Patients Without VAC
Piperacillin/tazobactam		
DDD/100 patient-days	6.54	7.48
Grams per patient	19.21	12.38
Meropenem		
DDD/100 patient-days	6.44	3.40
Grams per patient	2.70	0.80
Ciprofloxacin		
DDD/100 patient-days	3.04	1.37
Grams per patient	0.31	0.11
Vancomycin		
DDD/100 patient-days	4.19	4.28
Grams per patient	17.58	10.13

The defined daily dose for piperacillin/tazobactam, meropenem, ciprofloxacin, and vancomycin was 14, 2, 0.5, and 2 g, respectively [15]. To compare antibiotic use in gram per patient, a zero inflated negative binominal regression model was used. This model can take into account the large proportion of patients having zero antibiotic use and the length of stay in the intensive care unit for each patient.

Abbreviations: DDD, defined daily dose; NA, not applicable; VAC, ventilator-associated complications.

promising metric for internal quality assessment and external benchmarking, as well as a potential surrogate outcome for intervention studies in mechanically ventilated patients.

VAC is objective and easily recorded. FiO_2 and PEEP are unlikely to be manipulated in order to "game" the detection of VAC events. In many ICUs, particularly at large facilities in developed countries, electronic patient record systems are available, making automated detection of VAC feasible. Even in ICUs where electronic methods are unavailable, the manual detection of VAC events is straightforward. We found that using printed patient records for our study assessment took <3 minutes per patient.

Our data showed VAC events were due to "potential VAP" (VAC with positive culture of respiratory pathogens in respiratory specimens plus antibiotic prescription with intention to treat as VAP by intensivist) in 30.7% of cases, atelectasis in 16.3%, acute pulmonary edema in 11.8%, and acute respiratory distress syndrome in 6.5%. Medication prescribing patterns suggested the remaining events were also due to fluid overload and suspected respiratory infections even if the patients did not meet our strict criteria for acute pulmonary edema and/or pneumonia. Both VAP and non-VAP pulmonary complications can potentially harm patients. VAC surveillance allows a more comprehensive detection of those events compared with VAP monitoring alone. As such, we believe that VAC is a more suitable surveillance target in patients on mechanical ventilation than VAP.

There was greater use of broad-spectrum antibiotics in patients with VAC. These were likely prescribed for a clinical suspicion of VAP without subsequent de-escalation or cessation, as diagnosis confirmation and identification of the causative pathogen is sometimes difficult. We support calls for improved diagnostic methods (such as the use of pneumonia-specific biomarkers) for VAP [13].

There are several limitations to this study. First, this is a single-center retrospective study. The study institution did not perform cardiac surgery or solid organ transplantation, which may influence the incidence of pulmonary complications in patients receiving mechanical ventilation. Comparison between VAC and VAP was not performed in this study, as VAP surveillance is not routinely performed in the unit and objective retrospective surveillance with sufficient quality assurance was deemed unfeasible. Clinical explanations for VAC events shown in this study were based on retrospective chart review, with a significant proportion of unexplainable cases. However, very similar etiologies were found to those described by Klompas [14]. Although stratification by potential confounding variables shown in Table 5 did not affect results, it needs to be stressed that patients with VAC had more comorbidities (ie, chronic obstructive pulmonary diseases and acute kidney injury) (Table 3). Patients on nonconventional modes of mechanical ventilation such as airway pressure release ventilation, high-frequency oscillatory ventilation, or extracorporeal membrane oxygenation were not included in this study. Validation of the VAC definition in these patients is required. Although an association between VAC and increased mortality was demonstrated in a preliminary study by Klompas, it was not reproduced in this study. This may be explained by differences in patients' severity of illness between the 2 studies. The impact of VAC on mortality was also limited by the small sample size. Based on our study findings, 6700 patients would need to be included to have sufficient power to detect a significant increase in ICU mortality due to VAC, assuming an ICU mortality rate of 10% and a 25% increased risk of ICU death. Data on antibiotic use and fluid balance were only available over the entire study period and hence could not be reported separately for pre- and post-VAC periods. The direct impact of VAC on these parameters and vice versa consequently could not be determined. The data shown in Table 4 are descriptive only, and formal comparison of the groups is not appropriate because of the time-dependent nature of VAC status. Finally, the use of antibiotics is highly dependent on local factors. It remains unclear if the greater broad-spectrum antibiotic consumption in VAC patients would be common to other facilities. However, the study institution has a strict policy for the use of antibiotics, with prescription only by full-time intensive care specialists with regular and on-demand input by infectious disease specialists. Multidrug-resistant

bacteria such as methicillin-resistant *S. aureus*, extended-spectrum β-lactamase, or AmpC producers and carbapenem-resistant gram-negative bacteria are not endemic in the unit. Broad-spectrum antibiotic usage with agents such as carbapenems for VAC events may be even greater in settings where specialist input is limited or multidrug-resistant bacteria are more common clinical problems.

If VAC surveillance were endorsed by a hospital or quality improvement agency, it is important to consider what would be done with the data. There are a number of potential interventions that could foreseeably reduce VAC rates but which have not yet been specifically studied with VAC surveillance in mind. These could include VAP prevention bundles, fluid management protocols, or protective mechanical ventilation strategies. Ideally, VAC prevention bundles will be developed and tested to determine their impact on VAC, ICU length of stay, and ICU antibiotic use.

Our study shows that VAC is a simple and objectively defined parameter that allows the universal detection of pulmonary complications including VAP in mechanically ventilated patients. VAC is associated with longer duration of mechanical ventilation, longer ICU stays, and greater use of broad-spectrum antibiotics. VAC's simplicity, objectivity, and consistent association with adverse outcomes make it a promising metric to succeed VAP for measuring quality and safety of care in ventilated patients.

Notes

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All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

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