Temporal Trends of Ventilator-Associated Pneumonia Incidence and the Effect of Implementing Health-care Bundles in a Suburban Community

Shifang Ding, MD, PhD; Oguz Kilickaya, MD; Serkan Senkal, MD;
Ognjen Gajic, MD, FCCP; Rolf D. Hubmayr, MD, FCCP; and Guangxi Li, MD

Background: Recent changes in critical care delivery, including the widespread implementation of health-care bundles, were aimed at reducing complications of critical illness, in particular ventilator-associated pneumonia (VAP), but no population-based study evaluated its effectiveness.

Methods: Using a previously validated electronic medical record database, we identified adult (≥ 18 years old) critically ill patients from Olmsted County, Minnesota, requiring mechanical ventilation for ≥ 48 h from January 2003 to December 2009. Trained intensivists identified cases of VAP according to different established clinical definitions. The incidence and outcome of VAP was compared before and after implementation of the so-called "VAP bundle."

Results: The median age, severity of illness, proportion of surgical patients, and patients with neurologic disease increased over time ($P < .05$ for trend in all). Regardless of the definition used, the VAP rate remained similar throughout the study period and did not change with the introduction of the VAP bundle. According to previous Centers for Disease Control and Prevention criteria, the yearly estimates of the VAP incidence ranged between 7.1 and 10.4 cases per 1,000 ventilator-days, with an age-adjusted incidence of 3.1 vs 5.6 per 100,000 population ($P = .54$ for trends). Standardized hospital mortality ratio of patients at high risk to develop VAP significantly decreased from 1.7 (95% CI, 0.8-3.0) to 0.7 (95% CI, 0.3-1.4; $P = .0003$ for trend).

Conclusions: The incidence of VAP was unaffected by the implementation of the VAP bundle. Secular changes in hospital mortality are unlikely to be attributed to the VAP bundle per se.

CHEST 2013; 144(5):1461-1468

Abbreviations: APACHE = Acute Physiology and Chronic Health Evaluation; CCCTG = Canadian Critical Care Trials Group; CDC = Centers for Disease Control and Prevention; CPIS = clinical pulmonary infection score; ETT = endotracheal tube; IQR = interquartile range; LOS = length of stay; MV = mechanical ventilation; SMR = standard mortality ratio; SOFA = Sequential Organ Failure Assessment; VAE = ventilator-associated event; VAP = ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) is a common nosocomial infection, associated with prolonged mechanical ventilation (MV) and ICU stay, as well as increased attributable mortality and health-care cost.^{1,2}

Manuscript received July 4, 2012; revision accepted June 20, 2013.

Affiliations: From the Division of Pulmonary and Critical Care Medicine (Drs Ding, Kilickaya, Senkal, Gajic, Hubmayr, and Li), Mayo Epidemiology and Translational Research in Intensive Care, Mayo Clinic, Rochester, MN; the Division of Intensive Care Unit (Dr Ding), Qilu Hospital, Shandong University, Jinan, China; and the Division of Pulmonary Medicine (Dr Li), Guang An Men Hospital, China Academy of Chinese Medical Science, Beijing, China.

Funding/Support: This work was supported by the Mayo Foundation and the National Institutes of Health [Grant RC1LM 10468-1].

In 2004, the Institute for Healthcare Improvement published guidelines for the care of patients who were mechanically ventilated, assuming that they would prevent VAP. These guidelines came to be known as the "VAP bundle" (e-Table 1), and in 2006 they were implemented as a standard of care in many US hospitals. However, the evidence that the VAP bundle

Correspondence to: Guangxi Li, MD, Mayo Clinic, 200 First St SW, Rochester, MN 55905; e-mail: li.guangxi@mayo.edu

© 2013 American College of Chest Physicians. Reproduction of this article is prohibited without written permission from the American College of Chest Physicians. See online for more details.

DOI: 10.1378/chest.12-1675

prevents VAP remains controversial, in part because of the limited specificity of diagnostic criteria and, hence, heterogeneity in VAP definitions.^{3,4} In January 2013, the Centers for Disease Control and Prevention (CDC) rolled out new surveillance definitions for patients receiving MV to make VAP definition more objective.⁵ Until today, no data were published, to our knowledge, according to this newest VAP definition to evaluate the effect of VAP bundle. Moreover, neither VAP burden nor the general value of VAP prevention bundles has been evaluated in a population-based sample. To address these shortcomings of previous studies, we measured the trends in VAP incidence and outcome before and after the implementation of the VAP bundle in Olmsted County residents using all different well-established clinical definitions (e-*Fig 1*, e-*Table 2*).

MATERIALS AND METHODS

This is a retrospective, population-based cohort study. The study was approved by the institutional review board of Mayo Clinic, Rochester, Minnesota (10-006656).

Study Population

From January 2003 to December 2009, all consecutive adult (≥ 18 years) patients requiring invasive MV for ≥ 48 h were identified by an automated electronic search technique.⁶ Electronic medical records of identified patients were manually reviewed by a trained senior intensivist (S. D.) (*Fig 1*). Patients who (1) presented with or developed pneumonia within 48 h of MV, (2) were ventilated through a tracheostomy tube, (3) had been readmitted to the hospital within the past 90 days, (4) were immune deficient, or (5) refused permission to examine their medical records for research purposes were excluded.

ICU Settings

Mayo Medical Center serves as the only critical care provider in Olmsted County capable of delivering prolonged invasive MV. There are nine ICUs including 164 adult beds with completely separate rooms. In addition to routine hand hygiene, basic infection control protocols, and other patient care bundles,^{7,8} the Institute for Healthcare Improvement VAP bundle (e-*Table 1*) was integrated to patient care in December 2006. A VAP quality-improvement project targeted 100% VAP bundle compliance and a zero incidence of VAP. We, therefore, designated the time from January 2003

through December 2006 as the prebundle period and from January 2007 through December 2009 as the postbundle period.

VAP Identification

VAP was diagnosed clinically according to six different previous clinical definitions and the newly recommended ventilator-associated event (VAE) algorithm (e-*Fig 1*, e-*Table 2*): loose definition,⁹ rigorous definition,⁹ the clinical pulmonary infection score (CPIS) > 6 ,^{10,11} the Canadian Critical Care Trials Group (CCCTG) classification (possible type),¹² the International Sepsis Forum Consensus definition (probable type),¹³ the CDC criteria,¹⁴ and the new VAE algorithm.¹⁵ Patients receiving a diagnosis of VAP were further grouped as either early onset (≤ 4 days) or late onset (> 4 days).^{1,16} Only the first episode of VAP during the study period was included in the final analysis.

Data Collection

Additional information retrieved from medical records included demographic data, smoking habit, obesity ($\text{BMI} \geq 30 \text{ kg/m}^2$), main reasons for MV, comorbidity conditions (measured by Charlson index),¹⁷ severity of critical illness and organ dysfunction measured by APACHE (Acute Physiology and Chronic Health Evaluation) III score¹⁸ and Sequential Organ Failure Assessment (SOFA) score on the first day of ICU admission,¹⁹ bronchoscopy examination, microbiology data, reintubation, and tracheostomy. The predicted mortality rate for each patient was determined from the APACHE IV score calculated by the worst values obtained within 24 hours of ICU admission.

Outcomes

The primary outcome was the incidence of VAP. Secondary outcome measurement included time to onset of VAP, the duration of MV, hospital and ICU length of stay (LOS), and mortality in the ICU.

Statistical Analysis

Continuous variables were summarized as medians with interquartile ranges (IQRs) and categorical variables described as count and percentage. The Wilcoxon/Kruskal-Wallis test was used to compare continuous data, and χ^2 test or Fisher exact test was used for categorical data. Increasing (or decreasing) time trends for continuous VAP risk factors were tested using a linear trend test in an analysis of variance. Increasing (or decreasing) categorical risk factors were tested using a linear term for time in a logistic regression analysis. For calculating age- and sex-specific VAP incidence, the entire adult population of Olmsted County was considered at risk. A linear term for time and APACHE III on admission was entered in the multivariate logistic regression model to test the increasing or decreasing VAP incidence trends. Yearly standard mortality ratio (SMR) was calculated using the actual hospital deaths divided by median APACHE IV predicted deaths. Increasing (or decreasing) time trend for SMR was tested using a linear trend test, and Fisher exact test was used to compare prebundle and postbundle SMR. All statistical analyses were performed using JMP 9.0 (SAS Institute Inc). The *P* values $< .05$ were considered statistically significant.

RESULTS

A total of 684 patients from Olmsted County who received invasive MV for > 48 h were identified, of

FIGURE 1. Flowchart representing the study design. VAP = ventilator-associated pneumonia.

Table 1—The Baseline Characteristics and Outcome of Patients at Risk for VAP

Characteristic	2003 (n = 51)	2004 (n = 52)	2005 (n = 43)	2006 (n = 67)	2007 (n = 51)	2008 (n = 43)	2009 (n = 43)	P for Linear Trends		P for Prebundle (n = 213)	Postbundle (n = 137)	P for Prebundle/Postbundle
Admission characteristics												
Age, median (IQR), y	62 (43-77)	66 (52-78)	70 (60-82)	67 (47-78)	66 (46-81)	58 (46-69)	66 (43-79)	.07	66 (51-78)	63 (46-76)	.10	
Men	31 (61)	28 (54)	18 (42)	39 (58)	29 (57)	20 (47)	21 (49)	.35	97 (46)	67 (49)	.54	
Race								.14			.06	
White	44 (86)	46 (88)	40 (93)	58 (87)	41 (80)	35 (81)	35 (81)		188 (88)	111 (81)		
Non-white	7 (14)	6 (12)	3 (7)	9 (13)	10 (20)	8 (19)	8 (19)		25 (12)	26 (19)		
Obesity	25 (49)	13 (25)	15 (35)	25 (37)	22 (43)	11 (26)	18 (42)	.75	78 (37)	51 (37)	.91	
Charlson index, median (IQR)	3 (2-4)	3 (2-4)	4 (3-5)	4 (2-5)	3 (2-5)	4 (2-5)	4 (3-6)	.002	3 (2-4)	4 (2-5)	.03	
APACHE III, median (IQR)	35 (16-48)	66 (52-85)	76 (61-104)	76 (57-94)	83 (65-108)	86 (69-113)	91 (62-114)	< .0001	65 (43-88)	88 (66-109)	< .0001	
SOFA score, median (IQR)	1 (0-3)	4 (2-6.75)	5 (3-9)	7 (4-9)	7 (5-10)	7 (5-10)	7 (5-11)	< .0001	4 (2-7)	7 (5-10)	< .0001	
Surgical patients	34 (67)	35 (67)	24 (56)	43 (64)	33 (65)	23 (53)	31 (72)	.56	136 (64)	87 (64)	.95	
Enteral feeding	12 (24)	15 (29)	18 (42)	26 (39)	22 (43)	25 (58)	19 (44)	.0183	71 (33)	66 (48)	.007	
Main reason for MV												
Airway protection	17 (33)	11 (21)	9 (21)	22 (33)	15 (29)	17 (40)	8 (19)	.97	59 (28)	40 (29)	.76	
Repeat surgery or complication	22 (43)	29 (56)	19 (44)	19 (28)	19 (37)	15 (35)	22 (51)	.44	89 (42)	56 (41)	.87	
Diagnostic practice												
Daily CXRs	45 (88)	29 (56)	35 (81)	40 (60)	30 (59)	37 (86)	16 (37)	.0017	149 (70)	83 (61)	.07	
Bronchoscopy	5 (10)	6 (12)	3 (7)	8 (12)	10 (20)	8 (19)	11 (26)	.16	22 (10)	29 (21)	.005	
ETA	27 (53)	34 (65)	31 (72)	38 (57)	28 (55)	31 (72)	22 (51)	.84	130 (61)	81 (59)	.72	
Bacteria growth from ETA	22 (43)	19 (37)	16 (37)	27 (40)	17 (33)	18 (42)	8 (19)	.20	84 (39)	43 (31)	.12	
Outcome												
Duration of MV, median (IQR), d	4 (3-10)	6 (3-12)	4 (3-10)	4 (3-7)	6 (3-10)	7 (4-9)	6 (3-10)	.52 ^a	5 (3-9)	6 (3-10)	.13	
ICU LOS, median (IQR), d	9 (7-14)	10 (8-16)	10 (7-20)	8 (6-13)	7 (5-17)	12 (9-18)	11 (7-21)	.76 ^a	9 (6-15)	11 (6-18)	.30	
Hospital LOS, median (IQR), d	17 (10-27)	19 (10-37)	16 (10-26)	16 (10-21)	16 (9-27)	22 (12-34)	18 (12-39)	.92 ^a	16 (10-26)	19 (10-33)	.14	
Hospital death	10 (20)	12 (23)	12 (28)	15 (22)	11 (22)	7 (16)	7 (16)	< .000 ^a	49 (23)	25 (18)	< .0001	

Data are presented as No. (%) unless otherwise noted. APACHE = Acute Physiologic Assessment and Chronic Health Evaluation; CXR = chest radiograph; ETA = endotracheal aspirate; IQR = interquartile range; LOS = length of stay; MV = mechanical ventilation; SOFA = Sequential Organ Failure Assessment; VAP = ventilator-associated pneumonia.

*Adjustment with baseline APACHE III score.

whom 350 eligible patients at risk for VAP were subsequently evaluated (Fig 1). The patient characteristics are displayed in Table 1. The comorbidity, severity of illness, and organ dysfunction increased over the years and, therefore, differed significantly between the study periods. Although crude hospital mortality and SMR decreased over time ($P < .001$), the duration of MV and ICU LOS remained unchanged (Table 1).

Starting in 2007, the compliance with all elements of the VAP bundle was around 97%. The detailed compliance rate measured by our institution is displayed in e-Figure 2.²⁰ Late-onset VAP accounted for 73.1% (19 of 26) to 86.7% (13 of 15) of cases, depending on the definitions (Table 2). Regardless of the definitions used, including the new CDC VAE algorithm, the VAP incidence remained similar throughout the study period and did not change with the introduction of the VAP bundle (Table 2). According to previous CDC criteria, the yearly estimates of the VAP incidence ranged between 7.1 and 10.4 cases per 1,000 ventilator-days, with an age-adjusted incidence of 3.1 vs 5.6 per 100,000 population ($P = .54$ for trends) (Fig 2). VAP estimates in the prebundle era averaged 9.0 cases per 1,000 ventilator-days, amounting to 4.2 cases per 100,000 adults living in Olmsted County. In comparison, estimates post bundle implementation were 10.1 cases per 1,000 ventilator-days and 3.9 per 100,000 adults, respectively (Fig 2).

VAP was significantly associated with longer duration of MV, intubation, and ICU and hospital LOS (Table 3). However, the VAP patient mortality did not significantly increase when compared with patients without VAP at risk ($P = .80$).

DISCUSSION

In this population-based cohort, the VAP incidence remained unchanged during the 7-year study period and was not affected by the implementation of the so-called "VAP bundle." During the same time span, the severity of illness of patients at risk for VAP increased, while the severity-adjusted mortality decreased significantly. The VAP bundle compliance rate remained high after the bundle implementation. This observation from our community cohort did not support the previously reported decline in VAP incidence following the bundle implementation.²¹⁻²⁴ Several reasons may potentially explain our results.

First, the diagnosis bias is one of the most significant factors affecting the incidence of VAP by different investigators. The clinical definitions for VAP are quite subjective and nonspecific. With the pressure of nonpayment from Medicare and Medicaid on hospital-acquired infections, many observers minimize

Table 2—Sensitivity Analysis of VAP Trends

Measure	P for Linear Trends (Adjusted P Value *)										P for Before/After
	2003 (n = 51)	2004 (n = 52)	2005 (n = 43)	2006 (n = 67)	2007 (n = 51)	2008 (n = 43)	2009 (n = 43)	Before VAP Bundle (n = 213)	After VAP Bundle (n = 137)		
Loose definition	5 (10)	3 (6)	3 (7)	4 (6)	4 (8)	4 (9)	3 (7)	.98 (.47)	15 (7)	11 (8)	.73
Rigorous definition	3 (6)	2 (4)	2 (5)	2 (3)	2 (3)	2 (5)	2 (5)	.99 (.76)	9 (4)	6 (4)	.94
CPIS > 6	4 (8)	2 (4)	3 (7)	3 (4)	3 (6)	3 (7)	2 (5)	.97 (.73)	12 (6)	8 (6)	.94
CCCTG classification	5 (10)	3 (6)	3 (7)	4 (6)	4 (8)	4 (9)	3 (7)	.98 (.47)	15 (7)	11 (8)	.73
ISF definition	5 (10)	3 (6)	3 (7)	4 (6)	3 (6)	3 (7)	3 (7)	.84 (.70)	15 (7)	9 (7)	.86
CDC criteria	5 (10)	3 (6)	3 (7)	4 (6)	4 (8)	4 (9)	3 (7)	.98 (.47)	15 (7)	11 (8)	.73
New CDC Ventilator-associated events surveillance definition											
VAC	9 (18)	5 (10)	5 (12)	5 (7)	8 (16)	3 (7)	4 (9)	.28 (.29)	24 (11)	15 (11)	.99
IVAC	4 (8)	1 (2)	1 (2)	1 (1)	4 (8)	0 (0)	2 (5)	.74 (.63)	7 (3)	6 (4)	.58
Probable and possible VAP	2 (4)	0 (0)	0 (0)	1 (1)	4 (8)	0 (0)	2 (5)	.40 (.35)	3 (1)	6 (4)	.16

Data are presented as No. (%). P for linear trends adjusted by baseline severity of illness. CCCTG = Canadian Critical Care Trials Group; CDC = Centers for Disease Control and Prevention; CPIS = clinical pulmonary infection score; ISF = International Sepsis Forum Consensus; IVAC = infection-related ventilator-associated complication; VAC = ventilator-associated condition. See Table 1 legend for expansion of other abbreviations.

FIGURE 2. The trends of VAP incidence were calculated by three different methods, according to previous Centers for Disease Control and Prevention criteria in Olmsted County, Minnesota. See Figure 1 legend for expansion of abbreviation.

their VAP rates through applying subjective criteria more and more strictly, leading to lower and lower VAP rates. Some ICUs in the United States claimed a near-zero VAP rate,²¹⁻²⁶ which was more likely attributed to the strong financial pressures on hospitals to minimize their VAP rates rather than an actual improvement in health-care management. Although variability in VAP diagnosis can be influenced by the technique used to obtain microbiologic specimens, similar to other settings, our surveillance data showed that bronchoscopy examination and quantitative culture of endotracheal aspiration was not routinely performed in clinical practice.²⁷ Therefore, to control the confounding effect of different clinical definitions, all seven major published VAP definitions, including the newest CDC surveillance algorithm, were used in our study. We found the similar sensitivity to identify patients with VAP using a loose definition,⁹ CCCTG classification,¹² and the old CDC criteria,¹⁴ whereas almost 50% of patients with VAP would be excluded according to the rigorous definition,⁹ and only one-third would be left using the newest CDC VAP definition (e-Fig 3). Finally, we used old CDC criteria to report the incidence trends, since they had better agreement between different reviewers.¹⁴ Regardless of which definition we used, no significant beneficial effect of VAP bundle was observed in our study.

Second, the adherence to specific bundle elements before the implementation was not carefully recorded, which might veil the VAP bundle effect. Some elements (protocols for weaning and sedation) have already been in practice in study ICUs. In the previously published prospective data from a single (medical) ICU, the adherence to VAP bundle elements

ranged from 60% for head of the bed elevation to close to a 100% for stress ulcer prophylaxis and sedation interruption.²⁸ We can only speculate that the lack of effect after administrative introduction of the VAP bundle may in part be explained by already high adherence to bundle elements. This may also explain a lower prebundle incidence than previously published reports.^{21-23,26} Although a checklist approach may lead to a higher compliance with health-care bundles,²⁹⁻³¹ their effect on the prevention of VAP occurrence is affected by different implementation strategies.^{23,25}

Another important point is that with only approximately 45 patients per year, the rates in any 1-year period are intrinsically unstable and may adversely influence the analysis. The small sample size limited the ability to detect the effect of the VAP bundle, particularly in the academic institution where local practice improvements were in place long before the introduction of administrative requirements.

Finally, the prolonged endotracheal intubation and subsequent aspiration of secretions around the endotracheal tube (ETT) cuff are the major and not easily preventable determinants of VAP development. In our study, the proportion of patients who required continued airway protection and repeat surgery or surgical complication remained unchanged over the years and were the major reasons for prolonged MV in patients with VAP.^{22,23,32} In these circumstances, daily sedation vacation and readiness for earlier extubation may play a less important role in the reduction of VAP incidence.^{33,34} Moreover, the increased use of gastric suppression and enteral nutrition might also worsen the effects of the VAP bundle because of the risk of aspiration of gastric contents.³⁴⁻³⁶ Although

Table 3—Baseline Characteristics and Outcomes of Patients With VAP and Those Without VAP

Characteristic or Outcome	Non-VAP (n = 324)	VAP (n = 26)	P Value
Age, median (IQR), y	66 (49-78)	51 (32-71)	.0159
Male	173 (53)	13 (50)	.74
Race			.77
White	276 (85)	23 (88)	
Non-white	48 (15)	3 (12)	
Obesity	119 (37)	10 (38)	.86
Smoking habit	128 (40)	8 (31)	.38
Charlson comorbidity index, median (IQR)	3 (2-5)	3 (2-5.25)	.81
APACHE III score, median (IQR)	73 (51-98)	69 (42-85)	.15
SOFA score at day 1, median (IQR)	6 (4-9)	5 (1-7)	.27
MV reason			.0068
Acute asthma/AECOPD	30 (9)	0	
CHF	29 (9)	0	
ARDS	44 (14)	3 (12)	
Airway protection	84 (26)	15 (58)	
Delay weaning after surgery	137 (42)	8 (30)	
Surgical patients	208 (64)	15 (58)	.51
IABP	26 (8)	0	.13
CRRT	32 (10)	2 (8)	.72
Enteral feeding	122 (38)	15 (58)	.0440
Daily CXRs	209 (64.51)	23 (88.46)	.0129
Bronchoscopy examination	41 (13)	10 (38)	.0003
ETA	186 (57)	25 (96)	.0001
Bacteria growth from ETA	107 (32)	20 (77)	< .0001
Reintubation	27 (8)	7 (27)	.0021
Tracheostomy	49 (15)	9 (35)	.0101
Time to tracheostomy, median (IQR), d	7.5 (5-12)	11.2 (10-18)	.0222
Duration of MV, median (IQR), d	5 (3-9)	9 (5-14)	.0003
ICU LOS, median (IQR), d	9 (6-16)	14 (10-21)	.0026
Hospital LOS, median (IQR), d	17 (10-28)	22 (15-51)	.0145
Hospital deaths	69 (21)	5 (19)	.80

Data are presented as No. (%) unless otherwise noted. AECOPD = acute exacerbation of COPD; CHF = congestive heart failure; CRRT = continuous renal replacement therapy; IABP = intraaortic balloon pump. See Table 1 legend for expansion of other abbreviations.

controversial,³⁷ additional measures to reduce the accumulation of subglottic secretions above the ETT cuff (subglottic secretions drainage) may be necessary to further reduce VAP incidence. Bacterial colonization and subsequent biofilm formation inside the ETT lumen is another important etiologic mechanism of VAP in patients who require prolonged intubation.³⁸ Late-onset VAP was the main type of VAP, which was associated with nonmodifiable patient-related factors in our study.³⁹ The use of silver-coated ETTs may further decrease VAP incidence in patients at high risk.⁴⁰ Zero or near-zero VAP rate may not be possible,⁴¹⁻⁴³ even with the implementation of subglottic secretions drainage and silver-coated tubes.^{37,40} Some authors reported a dramatic decrease in VAP rates after initi-

ation of VAP bundles: from 19.3 to 21.2 cases to near zero or zero cases per 1,000 ventilator-days.²¹⁻²⁶ However, none of these studies reported the mortality benefit or other VAP-related outcome benefits, which were essential end points to evaluate the intervention effects.⁴⁴ Therefore, we could not exclude a potential underreporting of VAP episodes by observers, given the pressure to report VAP rate as benchmark for quality of patient care.^{4,45-47}

Although critically ill Olmsted County residents at risk for VAP presented with increasing severity of illness scores, the patient mortality significantly decreased after the implementation of a series of health-care bundles,^{6,8,48} whereas the duration of MV and ICU and hospital LOS did not change. Multiple quality-improvement interventions have been implemented in the study of ICUs, and these secular changes in mortality are unlikely to be explained by the implementation of the VAP bundle per se.

Our study certainly had several potential limitations. First, this study was an observational and retrospective design. No causal effect could be determined in such a study design. Second, the data represented a cohort study from a single community. It might not be generalized to other regions. Third, despite the use of seven different VAP definitions, the misclassification bias in the diagnosis of VAP could not be excluded.⁴⁹ Our VAP definition only includes patients using the ventilator > 48 h; some patients might be missed according to the old CDC criteria. Fourth, the study did not exploit the effect of the use of antibiotics to control other infective sources on the reduction of VAP occurrence. Most importantly, the lack of detailed bundle adherence rate data over time limited our ability to judge the meaningful health-care change after the bundle implementation.

CONCLUSIONS

The implementation of a VAP prevention bundle in a suburban community did not affect VAP incidence. It was associated with decreased hospital mortality.

ACKNOWLEDGMENTS

Author contributions: Dr Li is the guarantor of the manuscript and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Dr Ding: contributed to writing the protocol, collecting and analyzing the data, and drafting the manuscript.

Dr Kilickaya: contributed to collecting and analyzing the data and revising the manuscript.

Dr Senkal: contributed to collecting and analyzing the data and revising the manuscript.

Dr Gajic: contributed to conception of the idea and study design, approval of the final draft of the protocol, study monitoring, final data analyses, interpretation of results, and review of the completed manuscript.

Dr Hubmayr: contributed to conceiving and revising the completed manuscript.

Dr Li: contributed to study design, collection of electronic data, statistical analysis, and review of the completed manuscript draft.

Financial/nonfinancial disclosures: The authors have reported to *CHEST* that no potential conflicts of interest exist with any companies/organizations whose products or services may be discussed in this article.

Role of sponsors: The sponsors had no role in the design of the study, the collection and analysis of the data, or in the preparation of the manuscript.

Other contributions: We thank Enrique Ortiz Diaz, MD; Ahmad R. Nusair, MS; Sonal G. Rachmale, MS; and Man Li, MD, for their help. We also thank Jody Clikeman for her editorial assistance. The study was performed at Mayo Clinic, Rochester, Minnesota.

Additional information: The e-Figures and e-Tables can be found in the "Supplemental Materials" area of the online article.

REFERENCES

- 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.
- Kollef MH, Morrow LE, Niederman MS, et al. Clinical characteristics and treatment patterns among patients with ventilator-associated pneumonia. *Chest*. 2006;129(5):1210-1218.
- Marquette CH, Copin MC, Wallet F, et al. Diagnostic tests for pneumonia in ventilated patients: prospective evaluation of diagnostic accuracy using histology as a diagnostic gold standard. *Am J Respir Crit Care Med*. 1995;151(6):1878-1888.
- Uçkay I, Ahmed QA, Sax H, Pittet D. Ventilator-associated pneumonia as a quality indicator for patient safety? *Clin Infect Dis*. 2008;46(4):557-563.
- National healthcare safety network: Surveillance for ventilator-associated events. Centers for Disease Control and Prevention website. <http://www.cdc.gov/nhsn/acute-care-hospital/vae/index.html>. Published April 1, 2013. Accessed April 15, 2013.
- Li G, Malinchoc M, Cartin-Ceba R, et al. Eight-year trend of acute respiratory distress syndrome: a population-based study in Olmsted County, Minnesota. *Am J Respir Crit Care Med*. 2011;183(1):59-66.
- Barth MM, Oyen LJ, Warfield KT, et al. Comparison of a nurse initiated insulin infusion protocol for intensive insulin therapy between adult surgical trauma, medical and coronary care intensive care patients. *BMC Emerg Med*. 2007;7:14.
- Schramm GE, Kashyap R, Mullon JJ, Gajic O, Afessa B. Septic shock: a multidisciplinary response team and weekly feedback to clinicians improve the process of care and mortality. *Crit Care Med*. 2011;39(2):252-258.
- Tejerina E, Esteban A, Fernández-Segoviano P, et al. Accuracy of clinical definitions of ventilator-associated pneumonia: comparison with autopsy findings. *J Crit Care*. 2010;25(1):62-68.
- Fartoukh M, Maitre B, Honoré S, Cerf C, Zahar JR, Brun-Buisson C. Diagnosing pneumonia during mechanical ventilation: the clinical pulmonary infection score revisited. *Am J Respir Crit Care Med*. 2003;168(2):173-179.
- Zilberberg MD, Shorr AF. Ventilator-associated pneumonia: the clinical pulmonary infection score as a surrogate for diagnostics and outcome. *Clin Infect Dis*. 2010;51(suppl 1):S131-S135.
- Canadian Critical Care Trials Group. A randomized trial of diagnostic techniques for ventilator-associated pneumonia. *N Engl J Med*. 2006;355(25):2619-2630.
- Calandra T, Cohen J; International Sepsis Forum Definition of Infection in the ICU Consensus Conference. The international sepsis forum consensus conference on definitions of infection in the intensive care unit. *Crit Care Med*. 2005;33(7):1538-1548.
- Horan TC, Andrus M, Dudeck MA. CDC/NHSN surveillance definition of health care-associated infection and criteria for specific types of infections in the acute care setting. *Am J Infect Control*. 2008;36(5):309-332.
- National healthcare safety network: ventilator-associated event (VAE) calculator. Centers for Disease Control and Prevention website. <http://www.cdc.gov/nhsn/vae-calculator/index.html>. Accessed April 15, 2013.
- Trouillet JL, Chastre J, Vuagnat A, et al. Ventilator-associated pneumonia caused by potentially drug-resistant bacteria. *Am J Respir Crit Care Med*. 1998;157(2):531-539.
- Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis*. 1987;40(5):373-383.
- Afessa B, Keegan MT, Hubmayr RD, et al. Evaluating the performance of an institution using an intensive care unit benchmark. *Mayo Clin Proc*. 2005;80(2):174-180.
- Vincent JL, Moreno R, Takala J, et al. The SOFA (Sepsis-related Organ Failure Assessment) score to describe organ dysfunction/failure. On behalf of the Working Group on Sepsis-Related Problems of the European Society of Intensive Care Medicine. *Intensive Care Med*. 1996;22(7):707-710.
- Quality: ventilator-associated pneumonia (VAP). Mayo Clinic website. <http://www.mayoclinic.org/quality/vap.html>. Accessed January 13, 2013.
- Papadimos TJ, Hensley SJ, Duggan JM, et al. Implementation of the "FASTHUG" concept decreases the incidence of ventilator-associated pneumonia in a surgical intensive care unit. *Patient Saf Surg*. 2008;2:3.
- DuBose JJ, Inaba K, Shifflett A, et al. Measurable outcomes of quality improvement in the trauma intensive care unit: the impact of a daily quality rounding checklist. *J Trauma*. 2008;64(1):22-27.
- Zaydfudim V, Dossett LA, Starmer JM, et al. Implementation of a real-time compliance dashboard to help reduce SICU ventilator-associated pneumonia with the ventilator bundle. *Arch Surg*. 2009;144(7):656-662.
- 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.
- Hawe CS, Ellis KS, Cairns CJ, Longmate A. Reduction of ventilator-associated pneumonia: active versus passive guideline implementation. *Intensive Care Med*. 2009;35(7):1180-1186.
- Weireter LJ Jr, Collins JN, Britt RC, Reed SF, Novosel TJ, Britt LD. Impact of a monitored program of care on incidence of ventilator-associated pneumonia: results of a long-term performance-improvement project. *J Am Coll Surg*. 2009;208(5):700-704.
- Afessa B, Hubmayr RD, Vetter EA, et al. Bronchoscopy in ventilator-associated pneumonia: agreement of calibrated loop and serial dilution. *Am J Respir Crit Care Med*. 2006;173(11):1229-1232.
- Gajic O, Afessa B, Hanson AC, et al. Effect of 24-hour mandatory versus on-demand critical care specialist presence on quality of care and family and provider satisfaction in the intensive care unit of a teaching hospital. *Crit Care Med*. 2008;36(1):36-44.
- Afessa B, Keegan MT, Mohammad Z, Finkelman JD, Peters SG. Identifying potentially ineffective care in the sickest critically ill patients on the third ICU day. *Chest*. 2004;126(6):1905-1909.
- Cason CL, Tyner T, Saunders S, Broome L; Centers for Disease Control and Prevention. Nurses' implementation

- of guidelines for ventilator-associated pneumonia from the Centers for Disease Control and Prevention. *Am J Crit Care*. 2007;16(1):28-36.
31. Mullon JJ, Gajic O, Gali B, Ficalora RD, Kolars JC, Afessa B. The impact of adding 1 month of intensive care unit training in a categorical internal medicine residency program. *Crit Care Med*. 2009;37(4):1223-1228.
 32. Dallas J, Skrupky L, Abebe N, Boyle WA III, Kollef MH. Ventilator-associated tracheobronchitis in a mixed surgical and medical ICU population. *Chest*. 2011;139(3):513-518.
 33. Edwards JR, Peterson KD, Mu Y, et al. National Healthcare Safety Network (NHSN) report: data summary for 2006 through 2008, issued December 2009. *Am J Infect Control*. 2009;37(10):783-805.
 34. DeLegge MH. Aspiration pneumonia: incidence, mortality, and at-risk populations. *JPEN J Parenter Enteral Nutr*. 2002;26(suppl 6):S19-24.
 35. Artinian V, Krayem H, DiGiovine B. Effects of early enteral feeding on the outcome of critically ill mechanically ventilated medical patients. *Chest*. 2006;129(4):960-967.
 36. Reignier J, Mercier E, Le Gouge A, et al; Clinical Research in Intensive Care and Sepsis (CRICS) Group. Effect of not monitoring residual gastric volume on risk of ventilator-associated pneumonia in adults receiving mechanical ventilation and early enteral feeding: a randomized controlled trial. *JAMA*. 2013;309(3):249-256.
 37. Lacherade JC, De Jonghe B, Guezennec P, et al. Intermittent subglottic secretion drainage and ventilator-associated pneumonia: a multicenter trial. *Am J Respir Crit Care Med*. 2010;182(7):910-917.
 38. Huang SS, Septimus E, Kleinman K, et al; CDC Prevention Epicenters Program; AHRQ DECIDE Network and Healthcare-Associated Infections Program. Targeted versus universal decolonization to prevent ICU infection. *N Engl J Med*. 2013;368(24):2255-2265.
 39. Giard M, Lepape A, Allaouchiche B, et al. Early- and late-onset ventilator-associated pneumonia acquired in the intensive care unit: comparison of risk factors. *J Crit Care*. 2008;23(1):27-33.
 40. Kollef MH, Afessa B, Anzueto A, et al; NASCENT Investigation Group. Silver-coated endotracheal tubes and incidence of ventilator-associated pneumonia: the NASCENT randomized trial. *JAMA*. 2008;300(7):805-813.
 41. Klompas M. Ventilator-associated pneumonia: is zero possible? *Clin Infect Dis*. 2010;51(10):1123-1126.
 42. Set a goal of zero central line and VAP infections. Determining what is really preventable. *Hosp Peer Rev*. 2008;33(1):4-5.
 43. Carlet J, Fabry J, Amalberti R, et al. The "zero risk" concept for hospital-acquired infections: a risky business! *Clin Infect Dis*. 2009;49(5):747-749.
 44. Schultz MJ. Ventilator-associated pneumonia reduced-mortality untouched. *Crit Care Med*. 2013;41(6):e96-e97.
 45. Klompas M, Platt R. Ventilator-associated pneumonia—the wrong quality measure for benchmarking. *Ann Intern Med*. 2007;147(11):803-805.
 46. Lee GM, Kleinman K, Soumerai SB, et al. Effect of nonpayment for preventable infections in US hospitals. *N Engl J Med*. 2012;367(15):1428-1437.
 47. Klompas M. Complications of mechanical ventilation—the CDC's new surveillance paradigm. *N Engl J Med*. 2013;368(16):1472-1475.
 48. Afessa B, Gajic O, Keegan MT, Seferian EG, Hubmayr RD, Peters SG. Impact of introducing multiple evidence-based clinical practice protocols in a medical intensive care unit: a retrospective cohort study. *BMC Emerg Med*. 2007;7:10.
 49. Lin MY, Bonten MJ. The dilemma of assessment bias in infection control research. *Clin Infect Dis*. 2012;54(9):1342-1347.