Implementation of Clinical Practice Guidelines For Ventilator-Associated Pneumonia: A Multicenter Prospective Study*

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Objective: Ventilator-associated pneumonia is an important cause of morbidity and mortality in critically ill patients. Evidence-based clinical practice guidelines for the prevention, diagnosis, and treatment of ventilator-associated pneumonia may improve outcomes, but optimal methods to ensure implementation of guidelines in the intensive care unit are unclear. Hence, we determined the effect of educational sessions augmented with reminders, and led by local opinion leaders, as strategies to implement evidence-based ventilator-associated pneumonia guidelines on guideline concordance and ventilator-associated pneumonia rates.

Design: Two-year prospective, multicenter, time-series study conducted between June 2007 and December 2009.

Setting: Eleven ICUs (ten in Canada, one in the United States); five academic and six community ICUs.

Patients: At each site, 30 adult patients mechanically ventilated >48 hrs were enrolled during four data collection periods (baseline, 6, 15, and 24 months).

Intervention: Guideline recommendations for the prevention, diagnosis, and treatment of ventilator-associated pneumonia were implemented using a multifaceted intervention (education, reminders, local opinion leaders, and implementation teams) directed toward the entire multidisciplinary ICU team. Clinician exposure to the intervention was assessed at 6, 15, and 24 months after the introduction of this intervention.

Measurements and Main Results: The main outcome measure was aggregate concordance with the 14 ventilator-associated pneumonia guideline recommendations. One thousand three hundred twenty patients were enrolled (330 in each study period). Clinician exposure

*See also p. 329.

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to the multifaceted intervention was high and increased during the study: 86.7%, 93.3%, 95.8%, ($p < .001$), as did aggregate concordance (mean [SD]): 50.7% (6.1), 54.4% (7.1), 56.2% (5.9), 58.7% (6.7) ($p = .007$). Over the study period, ventilator-associated pneumonia rates decreased (events/330 patients): 47 (14.2%), 34 (10.3%), 38 (11.5%), 29 (8.8%) ($p = .03$).

Conclusions: A 2-yr multifaceted intervention to enhance ventilator-associated pneumonia guideline uptake was associated with a significant increase in guideline concordance and a reduction in ventilator-associated pneumonia rates. (*Crit Care Med* 2013; 41:15–23)
Key Words: guidelines; knowledge translation; patient safety; quality; ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) is associated with morbidity, mortality, and substantial healthcare costs (1–3). Prevention of VAP can reduce the burden of illness and associated resource consumption (4, 5). Inappropriate diagnostic and management strategies related to VAP are associated with worse patient outcomes (6, 7). Translation of research evidence into practice has the potential to reduce the prevalence of VAP and improve patient management. Clinical practice guidelines can address this barrier by synthesizing the evidence into a more accessible format (8).

In a systematic review of guideline implementation strategies outside the critical care setting, Grimshaw and colleagues (9) found that most interventions improved the delivery of care, but the effect on patient outcomes varied. Furthermore, single-faceted interventions such as education, reminders, distribution of educational materials, and didactic lectures were associated with transient improvements in processes of care but not sustained behavior change or improved clinical outcomes. These authors postulated that a multifaceted intervention with carefully selected active strategies (e.g., targeted interactive education, reminders, prompts) may be additive and achieve greater impact (9). Specifically, reminders integrated with workflow (e.g., patient bedside rounds) and opinion leaders may add to the effectiveness of educational efforts (10, 11). However, interventions shown to be effective outside the critical care setting may not generalize to the complex, dynamic ICU environment.

Studies of guideline implementation in the ICU have yielded modest and inconsistent effects on clinician knowledge, attitudes, and behavior and on processes of care, patient outcomes, and costs (12–17). Although education was the common intervention in these studies, other potentially synergistic strategies such as reminders and opinion leaders were used variably, and no study used all of them (18–20). Furthermore, no studies targeted all members of the ICU team, customized the intervention to individual sites, or measured implementation fidelity (21, 22) and guideline concordance (23).

Given the limitations of the current literature regarding knowledge translation related to VAP, our objective was to determine the effect of educational strategies augmented with reminders, and led by local opinion leaders, as strategies to facilitate the implementation of evidence-based VAP guidelines (24, 25) on guideline concordance and VAP rates. The primary outcome was change in the aggregate concordance with the VAP guideline recommendations over the study duration. We hypothesized that an intensive intervention targeted to the entire ICU team, adapted to local practitioners, and optimized iteratively over the study period would be associated with a sustained increase in concordance with guideline recommendations and that these changes would be associated with decreased VAP rates.

METHODS

Study Design and Participating ICUs

We conducted a prospective, multicenter, time-series study over 24 months in a representative sample of 11 medical/surgical/trauma ICUs (ten in Canada, one in the United States; five academic and six community ICUs) without a pre-existing explicit approach for VAP guideline implementation. In each ICU, 30 consecutive adults (age >16 yrs) mechanically ventilated for >48 hrs were enrolled during the baseline and each of the three follow-up data collection periods. The intervals between data collection periods were initially planned for 6 months, but after the second period were increased to 9 months to allow for adequate time to implement the planned interventions. Hence, data were collected for a total of 330 patients across 11 sites for each data collection period: baseline, 6 months, 15 months, and 24 months, between June 1, 2007, and December 1, 2009. We chose a time-series design to assess: a sequential process of optimization, the penetration of our intervention over time, and the effect on our primary outcome of concordance with VAP guideline recommendations (24, 25). A 2-yr period was selected to allow time to change behavior and to determine the sustainability of our interventions.

Multifaceted Knowledge Translation Intervention

The 14 evidence-based recommendations for VAP prevention, diagnosis, and treatment were developed by a multidisciplinary panel of nurses, respiratory therapists, intensivists, infectious disease specialists, and public health officials (22, 23). These recommendations (**eTable 1**, Supplemental Digital Content 1, http://links.lww.com/CCM/A502) were implemented using a multifaceted intervention targeted to the entire ICU team but modified for each clinician group (nurses, respiratory therapists, physicians, pharmacists). The educational strategy consisted of a standardized presentation delivered in electronic, paper, and web-based formats, frequently asked questions, selected VAP primary publications, the published VAP guidelines (24, 25), and a web-based self-assessment quiz. Reminders included a bedside rounds checklist and monthly newsletters that focused on one of the recommendations. Local opinion leaders and a multidisciplinary guideline implementation team were responsible for site implementation of the educational strategy

and reminders (eMethods and **eTable 2**, Supplemental Digital Content 1, http://links.lww.com/CCM/A502).

A 1-day workshop was held before the study to distribute educational materials, introduce change concepts, and discuss guideline use. The initial implementation strategy was standardized; local implementation teams distributed bedside materials and introduced the reminders after baseline data collection. Sites were encouraged to share experiences through a Google group. Throughout the study, the study investigators helped site personnel overcome implementation difficulties (e.g., conference calls to troubleshoot site-specific problems, new educational tool development, site visits to provide rounds) and modify the interventions based on the results of site-specific surveys administered to ICU clinicians about their exposure to and assessment of the interventions.

Exposure to Guideline Recommendations and Multifaceted Knowledge Translation Intervention

Implementation fidelity was evaluated by a self-administered paper survey to determine clinician exposure to the VAP recommendations and components of the multifaceted intervention. Clinicians were asked to assess the educational materials and indicate desired changes to content or frequency of exposure. The survey was administered to all staff after the first, second, and third data collection periods, and the results were discussed with each team to determine changes for subsequent implementation periods. Changes, which were implemented by the local guideline implementation teams, included repeating group or individual teaching, increasing exposure to, and reinforcing use of, bedside educational materials and checklists, increasing exposure to monthly reminder newsletters, providing incentives to use the Web-based quiz, incorporating VAP prevention measures on order sets, and integrating recommendations into bedside flow sheets.

Data Collection

Research coordinators collected data by direct observation or chart review in a standardized manner at each site on the implementation of the 14 VAP recommendations and the presence or absence of contraindications to each recommendation using criteria defined a priori. For direct observations, clinicians were unaware of the observation time; for example, data regarding semirecumbency were collected once daily during randomly assigned 2-hr periods. Data collected by chart review included patient characteristics (e.g., age, sex, comorbidities, severity of illness including Acute Physiologic and Chronic Health Evaluation and Sequential Organ Failure Assessment scores) and clinical outcomes. Institutional ICU characteristics and other nonstudy quality improvement initiatives were documented on questionnaires to ICU leaders. Organizational culture was measured by the organization and management of ICUs questionnaire administered to all healthcare professionals at study initiation (26, 27).

Outcomes

The primary outcome was the change from baseline to the 24-month assessment in aggregate concordance for all 14 recommendations. Concordance was defined as the sum of the number of patients who were either eligible and received a specific guideline recommendation or not eligible and did not receive a specific guideline recommendation divided by the total number of patients (28). Eligibility criteria for each recommendation were defined a priori. For recommendations that required daily data collection (e.g., semirecumbency), the numerator was assessed on each patient-day and the denominator was total number of patient-days. For other recommendations (e.g., ventilator circuit changes), we determined guideline concordance once per patient. The percent concordance with each guideline recommendation was calculated for each of the four data collection periods for each ICU. Aggregate concordance was calculated by averaging the 14 guideline-specific concordance rates within each ICU at each period (**eFig. 2** and **eTable 3** for example of calculation, Supplemental Digital Content 1, http://links.lww.com/CCM/A502).

Secondary outcomes included the change from baseline to 2 yrs in VAP rate, duration of mechanical ventilation, ICU and hospital length of stay, and ICU and hospital mortality. VAP rate was chosen as the main secondary outcome because nine of the 14 recommendations were related to VAP prevention. Clinically suspected VAP was defined as new or persistent infiltrates on a chest radiograph in a patient who had been mechanically ventilated for at least 48 hrs plus two of: abnormal white blood cell count, presence of fever or hypothermia, purulent sputum, and deterioration in gas exchange (29). Study patients were screened daily for these criteria; the diagnosis was confirmed by the attending physician and adjudicated after all data were collected by the site principal investigator. Thereafter, all suspected VAP cases were adjudicated centrally by the study co-principal investigators (J.M., T.S.) to confirm that the clinical course was compatible with VAP based on culture results, antibiotic response, and lack of other etiologies to explain the signs and symptoms (30).

Data Analysis

Patient characteristics are described at each of the four periods by counts and percentages for categorical variables, medians and quartiles for days in the hospital before ICU admission (as a result of its strong positive skew), and means with SDs for all other continuous variables. The statistical significance of change across time was assessed by the χ^2 test, Kruskal–Wallis test, and one-way analysis of variance, respectively. The scores for the organization and management of ICUs questionnaire reflect all the healthcare professionals or physicians who completed the survey at each institution and were aggregated to the ICU level, out of a total possible score of 5 for each domain.

As a result of the expected within-site dependence, all outcomes were averaged to the site level before analysis. For VAP, we also used logistic regression to estimate the adjusted site rates controlling for patient characteristics that changed over time. The paired *t* test was then used to assess the significance of the average of the 11 within-site changes from baseline to 2 yrs. Because each site enrolled 30 patients during each time period, this simple aggregated approach was

TABLE 1. Institutional Characteristics

Institutional Characteristics	
Number of hospital beds, mean (SD)	469.3 (163.7)
Setting ($n = 11$)	
Academic, *n* (%)	6 (54.5)
Community, *n* (%)	5 (45.5)
ICU type ($n = 11$)	
Medical and surgical, *n* (%)	11 (100)
No. of ICU beds, mean (SD)	18.5 (3.7)
ICU occupancy, mean % (SD)	82.6 (13.8)
Staffing, mean (SD)	
Attending physicians	6.8 (3.1)
Staff nurses	93.5 (25.1)
Respiratory therapists	29.4 (13.8)
Pharmacists	1.4 (1.0)
ICU nurse educators (full-time-equivalent)	1.1 (0.3)
Staff nurse/patient ratio	1.1:1 (0.2)
Respiratory therapist/patient ratio	1:8 (3.1)
Presence of a formal quality program (ICUs) ($n = 11$), *n* (%)	2 (18.2)
No. of protocols or guidelines at each site, mean (SD)	10.4 (1.8)
Organizational culture	
Total no. of surveys completed	794
No. of surveys completed per site, mean (SD)	72.2 (18.3)
No. of surveys completed per site by healthcare professionals, mean (SD)	67.5 (18.4)
No. of surveys completed per site by medical doctors, mean (SD)	4.6 (1.8)
Organization and management of ICU –healthcare professionals,[a] mean (SD)	3.4 (0.1)
Organization and management of ICU–medical doctor,[a] mean (SD)	3.7 (0.2)

[a]The scores for organization and management of ICU reflect all the healthcare professionals or medical doctors who completed the survey at each institution and are aggregated to the unit level. The results are out of a total possible score of 5.

efficient and valid even when the outcomes (such as VAP) were not normally distributed at the patient level (31). Nevertheless, for each outcome, we confirmed graphically that the 11 ICU change scores did not depart substantially from normality, and we also confirmed that the exact Wilcoxon's signed-rank test provided identical conclusions (not shown). This approach was modified slightly for the ICU and hospital length of stay outcomes. For these time-to-event outcomes, we report the patient level Kaplan–Meier quartiles per period, but the *p* values were obtained by applying the *t* test to the log of the 11 site-specific pre-/posthazard ratios. These log-hazard ratios were estimated by Cox proportional hazards models comparing the final and baseline assessment separately at each site. The upper quartile of the Kaplan–Meier estimates was undefined for ICU and hospital length of stay because <75% of patients were discharged alive. Patients who died in the ICU or hospital were considered to have never been discharged and were thus censored after the latest observed discharge time. This strategy treats death as a competing risk, which precludes eventual ICU or hospital discharge.

Pearson correlation coefficients were used to assess the association between change in aggregate concordance from baseline to 24 months and a priori selected site-level covariates including exposure to the behavior change strategy as measured in the surveys, ICU demographic/organizational factors, quality improvement activities, and clinician perception of ICU organizational culture. For significant univariate correlations, a multivariate analysis was planned using SAS version 9.2 (SAS Institute, Cary, NC). All *p* values were two-sided without adjustment for multiple comparisons.

The number of sites ($n = 11$) was selected to provide 85% power using a paired *t* test at a two-sided $\alpha = 0.05$ to detect a change in aggregate concordance from baseline to 24 months that is as large as the SD of the site-specific changes. Given the observed between-site SD, this equates to a 7.9% change in aggregate concordance.

The study was approved by the Research Ethics Board of each participating hospital. Because this was an observational study of a quality improvement initiative, consent from individual patients was waived.

RESULTS

All 11 ICUs completed the study enrolling 330 patients in each study period, for a total of 1320 patients. Institutional characteristics are described in **Table 1**. All ICUs had a medical director, nurse manager, and nurse educators and ten had a "closed" administrative structure; only two ICUs had an explicit ICU quality improvement program. We identified 10.4 (1.8) (mean [SD]) other guidelines or quality improvement initiatives, on topics other than VAP, in place in the participating ICUs. Patient characteristics (**Table 2**) at each site were similar over the four study periods except average age decreased by 3.3 yrs ($p = 0.05$) and enrollment Sequential Organ Failure Assessment decreased by 0.6 points ($p = 0.04$) from baseline to 24 months. Approximately three fourths of the patients had a medical diagnosis at ICU admission.

Guideline Concordance (Primary Outcome)

The aggregate site-level concordance with the 14 guideline recommendations across all sites increased significantly from baseline to 24 months: 50.7% (6.1) at baseline, 54.4% (7.1) at 6 months, 56.2% (5.9) at 15 months, and 58.7% (6.7) at 24 months ($p = 0.007$). The change in aggregate concordance across individual sites varied from −3.6% to 20.7% at 24 months. Five sites achieved at least 10% increase in aggregate concordance, whereas only three sites achieved >15%.

TABLE 2. Patient Characteristics

Characteristics	Baseline (*n* = 330)	6 Months (*n* = 330)	15 Months (*n* = 330)	24 Months (*n* = 330)	*p*
Age, mean (SD)	61.9 (16.7)	60.2 (17.4)	57.9 (17.5)	58.6 (16.8)	0.05
Sex, female (%)	42.1	34.8	41.5	41.5	0.18
ICU admission diagnosis, *n* (%)					
Medical	239 (72.4)	247 (74.8)	233 (70.6)	253 (76.7)	
Surgical: elective	30 (9.1)	33 (10.0)	21 (6.4)	20 (6.1)	0.07
Surgical: emergency	61 (18.5)	50 (15.2)	76 (23.0)	57 (17.3)	
Acute Physiologic and Chronic Health Evaluation II, mean (SD)	23.0 (7.8)	23.0 (6.9)	22.6 (7.7)	23.5 (7.7)	0.54
Comorbidities, mean (SD)	2.2 (1.8)	2.3 (1.8)	2.2 (1.9)	2.1 (1.7)	0.17
Sequential Organ Failure Assessment on day of enrollment, mean (SD)	4.9 (3.3)	4.6 (3.2)	4.2 (3.1)	4.3 (3.2)	0.04
Days in hospital before ICU admission, median [first quartile, third quartile]	0.5 [0.1, 2.9]	0.5 [0.1, 2.2]	0.4 [0.1, 2.0]	0.4 [0.1, 2.1]	0.21

The site that achieved the greatest increase (20.7%) also achieved the highest absolute value of concordance (75.0%) by 24 months (**Table 3**).

Significant improvements in guideline concordance were observed for three of the eight prevention recommendations (endotracheal tube with subglottic secretion drainage, chlorhexidine for oral care, semirecumbent position); the greatest increase was achieved for the use of chlorhexidine oral care at 44.5% (95% confidence interval [CI] 21.0–68.0; **Table 4**). Concordance with recommendations for the use of orotracheal intubation and closed suction systems was nearly 100% at baseline and remained high. Concordance with recommendations for frequency of heated humidifier changes was low at baseline (2.2%) and did not improve. There was high concordance with the recommendation regarding frequency of ventilator circuit change at baseline (83.3%) with no change over time. Baseline concordance with recommendations regarding use of heat and moisture exchangers was 54.2% and did not improve nor did concordance with recommendations regarding changing the suctioning system (14.2–6.7%; $p = 0.09$).

Concordance with recommendations regarding diagnosis of VAP did not change over time. Concordance with the

TABLE 3. Aggregate Guideline Concordance[a] For All 14 Recommendations by Site

Site Number	Baseline (%)	6 Months (%)	15 Months (%)	24 Months (%)	Change From Baseline to 24 Months (%)
1	48.7	61.1	53.8	59.4	10.7
2	49.4	53.9	54.6	50.4	1.0
3	52.0	47.3	49.7	56.3	4.3
4	46.3	50.4	60.1	53.3	7.0
5	55.7	43.3	51.2	55.6	–0.1
6	40.5	67.4	63.4	57.0	16.5
7	41.3	58.0	54.5	58.0	16.7
8	54.3	57.3	50.9	66.3	12.0
9	54.3	57.1	53.4	75.0	20.7
10	55.0	46.1	68.9	57.7	2.7
11	60.1	56.2	57.5	56.5	–3.6
Overall, mean % (95% confidence interval)	50.7 (46.6–54.8)	54.4 (49.6–59.2)	56.2 (52.2–60.1)	58.7 (54.2–63.2)	8.0 (2.7–13.3)

[a]Aggregate concordance is the guideline concordance for all 14 ventilator-associated pneumonia guideline recommendations.

TABLE 4. Guideline Concordance For Prevention Recommendations That Showed Significant Improvement

Recommendation	Baseline	6 Months	15 Months	24 Months	Change From Baseline to 24 Months (95% Confidence Interval)	p[a]
Recommendations that showed significant improvement						
Endotracheal tube with subglottic secretion drainage, %	35.6	50.4	60.5	58.3	22.7 (−0.3 to 45.6)	0.05
Semirecumbent position (45°), %	28.7	36.5	37.6	40.7	12.0 (1.4–22.5)	0.03
Chlorhexidine oral care, %	15.9	38.8	51.5	60.4	44.5 (21.0–68.0)	0.002
Recommendations that did not show significant improvement						
Oral route of intubation	99.0	100.0	100.0	100.0	0.11 (−0.14 to 0.36)	0.34
Closed endotracheal suctioning system	100.0	98.8	98.5	99.4	−0.61 (−1.51 to 0.30)	0.17
Frequency of ventilator circuit change	83.3	85.2	87.3	83.0	−0.30 (−25.3 to 24.7)	0.98
Frequency of change of endotracheal suctioning system	14.2	11.2	8.8	6.7	−7.6 (−16.6 to 1.5)	0.09
Frequency of change of airway humidification						
Frequency of change of heat and moisture exchange	54.2	20.2	23.0	36.0	−23.5 (−57.2 to 10.1)	0.11
Frequency of change of heated humidifier	2.2	21.3	7.4	2.8	0.5 (−4.1 to 5.2)	0.80

[a]Comparison of baseline vs. 24 months using paired *t* test.

recommendation to analyze an endotracheal aspirate associated with a clinical suspicion of VAP rather than a bronchoscopic specimen was high at baseline (100.0%) and did not change over time (91.7% at 24 months; $p = 0.11$). The use of bronchoscopy for suspected VAP was low throughout the study and did not change from baseline to study end: 11 of 100 (11.0%) vs. nine of 63 (14.3%) ($p = 0.69$).

We did not observe any significant changes in concordance with the three recommendations regarding antibiotic therapy (**Table 5**). There were no significant correlations identified between changes in aggregate concordance from baseline to 24 months and our a priori selected site-level covariates; therefore, a multivariate analysis was not done for this outcome variable.

Fidelity of Implementation

From all ICUs, a total of 473, 420, and 380 guideline implementation assessment surveys were returned for the 6-, 15-, and 24-months periods, respectively. Not all of the same staff would have worked during the survey administration periods; therefore, a formal response rate was not calculable. Exposure to any element of the multifaceted intervention rose from 86.7% at 6 months to 93.3% at 15 months and 95.8% at 24 months ($p = 0.001$ for difference between 6 and 24 months). Exposures to the guideline recommendations, frequently asked questions, and bedside illustrations were highest of all components, and exposure continued to increase for each to the end of the study. Approximately 50% of clinicians indicated that they received small group teaching, whereas only 25.5% and 25.3% of respondents indicated receipt of slide presentations by e-mail or during rounds, respectively. Regarding electronic media, 33.7% of respondents reported using the VAP web site by 24 months and 43.2% reported using the self-administered, web-based self-assessment quiz. The monthly reminder newsletter was received by 43.2% of respondents. At 24 months, 87.6% reported that the daily reminder checklist was implemented in their ICU.

Clinical Outcomes (Secondary Outcomes)

The prevalence of VAP varied within each site and across all sites (**eFig. 1**, Supplemental Digital Content 1, http://links.lww.com/CCM/A502). Overall, aggregated VAP rates (cases/total patients from all sites) declined over the four study periods: 47 (14.2%), 34 (10.3%), 38 (11.5%), and 29 (8.8%) ($p = 0.03$). This trend persisted if we adjusted for age and Sequential Organ Failure Assessment score, which tended to decrease over the study period (adjusted $p = 0.01$). When

TABLE 5. Guideline Concordance For Recommendations For Antibiotic Therapy

Recommendation	Baseline	6 Months	15 Months	24 Months	Change From Baseline to 24 Months (95% Confidence Interval)	*p*
Initiation of monotherapy for each VAP suspicion, %	53.7	46.3	57.2	60.9	7.2 (–22.4 to 36.8)	0.60
8 days of antibiotic therapy for VAP, %[a]	41.5 (8 ICUs)	48.6 (7 ICUs)	56.3 (9 ICUs)	51.0 (5 ICUs)	11.7 (–6.0 to 29.5)	0.13
Antibiotic discontinuation if VAP not present, %[b]	45.5 (9 ICUs)	75.0 (7 ICUs)	50.0 (8 ICUs)	76.7 (5 ICUs)	18.5 (–83.0 to 120.0)	0.60

VAP = ventilator-associated pneumonia.

[a]Concordance for this recommendation is only evaluable in patients who had an episode evaluable for 8 days of antibiotic therapy. The number of ICUs with at least one evaluable patient at each of the four time periods is indicated. Only the four ICUs with evaluable patients at both the first and last period contributed to the % change from baseline calculation;

[b]Concordance for this recommendation is only evaluable in patients who had an episode evaluable for the antibiotic discontinuation policy. The number of ICUs that contributed to each of the four periods is indicated. Only the four ICUs with evaluable patients at both the first and last period contributed to the % change from baseline calculation.

considering the differences between the first and last study period, there was no change in duration of ICU length of stay (median [Q1, Q3] days), 13.7 [7.4, undefined] days vs. 12.6 [7.4, undefined] days (hazard ratio 1.09; 95% CI 0.95–1.26; $p = 0.20$), duration of mechanical ventilation, 8.9 [4.6, 45.2] days vs. 8.1 [4.5, 28.3] days (hazard ratio 1.08; 95% CI 0.88–1.33; $p = 0.43$), or ICU mortality, (28.5 % vs. 25.4%, absolute risk reduction 3.0%; 95% CI −2.6% to 8.6%; $p = 0.26$). However, duration of hospital length of stay 62.0 [21.2, undefined] days vs. 43.5 [18.6, undefined] days (hazard ratio 1.29; 95% CI 1.04–1.60; $p = 0.02$) and hospital mortality 38.2% vs. 30.3% (absolute risk reduction 7.9%; 95% CI 1.1%–14.7%; $p = 0.03$) significantly decreased during the course of the study. Clinical outcomes for each study period are presented in **eTable 4** (Supplemental Digital Content 1, http://links.lww.com/CCM/A502).

DISCUSSION

This study demonstrates that the introduction of VAP guidelines using a multifaceted intervention incorporating education, reminders, local opinion leaders, and implementation teams was associated with a high degree of awareness of best practices and significant increases in concordance with guidelines. We achieved exposure to the intervention by targeting the entire multidisciplinary ICU team and maintained this exposure over the 2-yr study duration. The improvement observed was greater for recommendations about prevention of VAP than for recommendations about diagnosis or treatment of VAP.

Despite a high degree of awareness of best practices, the absolute level of guideline concordance at 24 months was only 58.7% (54.2–63.2), and the magnitude of change in mean concordance was 8.0% (2.7–13.3). Because concordance includes all patients who should receive a recommendation and those who should not, the goal in any group of patients should be close to 100%. Increasing clinician awareness of best practice over time was not associated with a parallel increase in concordances.

Guideline concordance appeared to vary by recommendation, clinician, and site. For some recommendations, institutions already had uniformly high concordance, which remained high. For other recommendations, significant improvement in concordance occurred but varied over time; for other recommendations, improvement did not occur despite physician awareness of best practice. An important implication of this research is that unaddressed barriers to guideline implementation may have existed at baseline or have developed during the study. These include barriers related to the characteristics of the guidelines (e.g., vague or complex statements), the implementation process (e.g., competing demands on clinician time), provider intent (e.g., disagreement with recommendations or lack of intent to implement them, information saturation or shift of attention to other guidelines and initiatives), and institutional factors (e.g., lack of equipment, changes in quality improvement priorities) (32). We recommend that individuals who are leading quality improvement initiatives assess practice at baseline to understand site-specific evidence-practice gaps, assess barriers, and then target these gaps and barriers. Because different clinical practices and clinician groups may have different barriers, assessment of these barriers with tailored interventions may have the greatest impact on change (11). At some sites, concordance deteriorated after initial improvement despite continuous efforts to improve concordance. Future research should incorporate long-term follow-up with periodic reassessment of these barriers because studies of short duration cannot assess sustainability.

Our study has several strengths. First, in contrast to previous implementation studies in the ICU, we used a multicenter study design and a multifaceted intervention targeted to the entire ICU team (33). Second, our study was of longer duration than previous studies of VAP. Third, we investigated the fidelity of our intervention, an important and underreported aspect of knowledge translation, by surveying ICU clinicians to ascertain whether the target individuals were reached. Fourth, we used concordance to measure the use of guideline recommendations,

rather than simply adherence to actions recommended, to take into account both those who should receive an intervention and those who should not. Fifth, we made iterative institution-specific changes to optimize our study intervention over the study period. We also used a rigorous, multistep, VAP adjudication process to minimize any bias in assigning VAP diagnoses. We limited the VAP prevention interventions in our study to the VAP guideline (24, 25), which included only randomized clinical trial evidence and, thus, did not include other measures such as hand hygiene and handwashing, which were already in place at participating sites. Finally, although recent studies have implemented interventions using computerized decision support systems (34), telecommunication strategies (35), or telemedicine expertise (36), the interventions we evaluated used components readily available in most ICUs without the need for a costly technical infrastructure.

An important limitation of this study is that sources of hidden bias and secular trends that could account for the associations observed may have occurred because we did not use a randomized controlled study design. However, an advantage of our study design is that it allowed us to assess and optimize our behavior change strategies over the study period. A further limitation was that the activity of the local implementation teams was variable and likely influenced the results. Although we attempted to optimize the intervention at each site, use of the different facets of the intervention was variable. Hence, we cannot ascertain whether any single facet had a greater effect than others or whether the components worked additively or synergistically. The workload and time to implement our intervention was high, and whether the implementation of the intervention was economically beneficial is unknown. This study underscores the challenges in implementing and sustaining complex guidelines with a large number of recommendations and suggests the need for dedicated local teams supported by infrastructure and financial resources to engage in such quality improvement activities. Finally, the study investigators provided some oversight and guidance to each site's guideline implementation team to help sites optimize the multifaceted intervention during the study period. This effort may be associated with larger effects than that which would be seen in usual clinical practice unless local quality improvement teams provide a similar investment.

CONCLUSIONS

Our intensive, multifaceted guideline implementation strategy consisting of education and reminders, implemented by a dedicated local implementation team, achieved high levels of exposure and improved the adoption of a complex, 14-recommendation VAP guideline and maintained these changes over 2 yrs. This improvement in concordance was associated with a significant decrease in VAP rates over the duration of the study. However, overall concordance with recommendations in the guideline was moderate, increased by only a small amount over time, and was variable across centers and time. We conclude that this education and reminder-based intervention is insufficient as a standalone strategy to change behavior in the ICU. Additional interventions such as assessment of local barriers to implementation and tailored interventions, although likely to be more expensive, may be required to further improve and sustain concordance with guideline recommendations.

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