ORIGINAL ARTICLE

The Preventability of Ventilator-associated Events

The CDC Prevention Epicenters Wake Up and Breathe Collaborative

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Abstract

Rationale: The CDC introduced ventilator-associated event (VAE) definitions in January 2013. Little is known about VAE prevention. We hypothesized that daily, coordinated spontaneous awakening trials (SATs) and spontaneous breathing trials (SBTs) might prevent VAEs.

Objectives: To assess the preventability of VAEs.

Methods: We nested a multicenter quality improvement collaborative within a prospective study of VAE surveillance among 20 intensive care units between November 2011 and May 2013. Twelve units joined the collaborative and implemented an opt-out protocol for nurses and respiratory therapists to perform paired daily SATs and SBTs. The remaining eight units conducted surveillance alone. We measured temporal trends in VAEs using generalized mixed effects regression models adjusted for patient-level unit, age, sex, reason for intubation, Sequential Organ Failure Assessment score, and comorbidity index.

Measurements and Main Results: We tracked 5,164 consecutive episodes of mechanical ventilation: 3,425 in collaborative units and 1,739 in surveillance-only units. Within collaborative units, significant increases in SATs, SBTs, and percentage of SBTs performed without sedation were mirrored by significant decreases in duration of mechanical ventilation and hospital length-of-stay. There was no change in VAE risk per ventilator day but significant decreases in VAE risk per episode of mechanical ventilation (odds ratio [OR], 0.63; 95% confidence interval [CI], 0.42–0.97) and infection-related ventilator-associated complications (OR, 0.35; 95% CI, 0.17–0.71) but not pneumonias (OR, 0.51; 95% CI, 0.19–1.3). Within surveillance-only units, there were no significant changes in SAT, SBT, or VAE rates.

Conclusions: Enhanced performance of paired, daily SATs and SBTs is associated with lower VAE rates.
Clinical trial registered with www.clinicaltrials.gov (NCT 01583413).

Keywords: ventilator-associated events; quality improvement; surveillance

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At a Glance Commentary

Scientific Knowledge on the Subject: The Centers for Disease Control and Prevention released novel surveillance definitions for ventilator-associated events (VAEs) in early 2013. VAEs affect about 5% of ventilated patients and are strongly associated with increased duration of mechanical ventilation and increased hospital mortality risk. VAEs have been proposed as quality metrics but little is known about their prevention.

What This Study Adds to the Field: This is the first prospective study of the preventability of VAEs. Twelve intensive care units participating in a longitudinal, multicenter quality improvement collaborative focused on increasing the implementation of paired, spontaneous awakening trials and spontaneous breathing trials were able to reduce VAE rates by 37%.

Mechanically ventilated patients are at risk for multiple complications of critical care including pneumonia, acute respiratory distress syndrome (ARDS), pulmonary edema, thromboembolism, delirium, and atelectasis. Traditionally, surveillance for complications of mechanical ventilation has been limited to ventilator-associated pneumonia (VAP). This metric has been criticized, however, because it is subjective, labor intensive, prone to bias, and accounts for only a small fraction of intensive care unit (ICU) morbidity (1–3). In response to these concerns, the CDC collaborated with professional societies to develop new surveillance targets called "ventilator-associated events" (VAEs) (4, 5). The CDC's National Healthcare Safety Network replaced their VAP definitions with VAE definitions in early 2013. Over 1,500 U.S. hospitals currently report VAE data to the CDC.

VAE definitions were designed to identify episodes of sustained respiratory deterioration after a period of stability or improvement. The VAE framework includes a hierarchy of surveillance targets (Figure 1). The primary target is called a "ventilator-associated condition" (VAC) and is defined as greater than or equal to 2 days of increased ventilator settings after greater than or equal to 2 days of stable or decreasing settings (4). There are then secondary criteria to flag the subset of VACs that might be infection-related ventilator-associated complications (IVAC) and those that might be pneumonias (4).

VAC and IVAC have been proposed as potential metrics for benchmarking and pay-for-performance programs. Most organizations have deferred using the definitions for these purposes, however, because there are very few data at present about whether, how, and to what extent VAEs are preventable. Indeed, some have hypothesized that VAEs are simply surveillance markers for preexisting morbid illnesses rather than preventable complications (6, 7). Data on the preventability of VAEs are therefore urgently needed.

We prospectively evaluated the preventability of VAEs. We reasoned that the best way to prevent VAEs would be to decrease exposure to mechanical ventilation by speeding time to extubation. Minimizing sedation and regularly assessing patients' readiness for extubation have repeatedly been shown to speed liberation from mechanical ventilation (8, 9). Minimizing sedation may also have collateral benefits because high levels of sedation are independently associated with multiple infectious and noninfectious complications (10, 11). We therefore organized a multicenter collaborative to test the preventability of VAEs by enhancing the consistency, reliability, and coordination of daily spontaneous awakening trials (SATs) and spontaneous breathing trials (SBTs). Some of the results of this study have been previously reported in the form of an abstract (12).

Methods

Overview

We nested the collaborative within a prospective surveillance study of VAE epidemiology. The surveillance study included 20 ICUs affiliated with 13 academic and community hospitals. Twelve ICUs elected to participate in the collaborative ("collaborative units") and eight did not ("surveillance-only units"). All units, however, collected the same data on all patients using the same definitions and entered the data into a common web-based data-entry system. We were therefore able to follow changes in VAE incidence, SAT and SBT performance rates, and other outcomes using comparable methods in both collaborative and surveillance-only units. We did not directly compare performance and outcome rates between collaborative participants and nonparticipants, however, because participation in the collaborative was not randomized and there were substantial

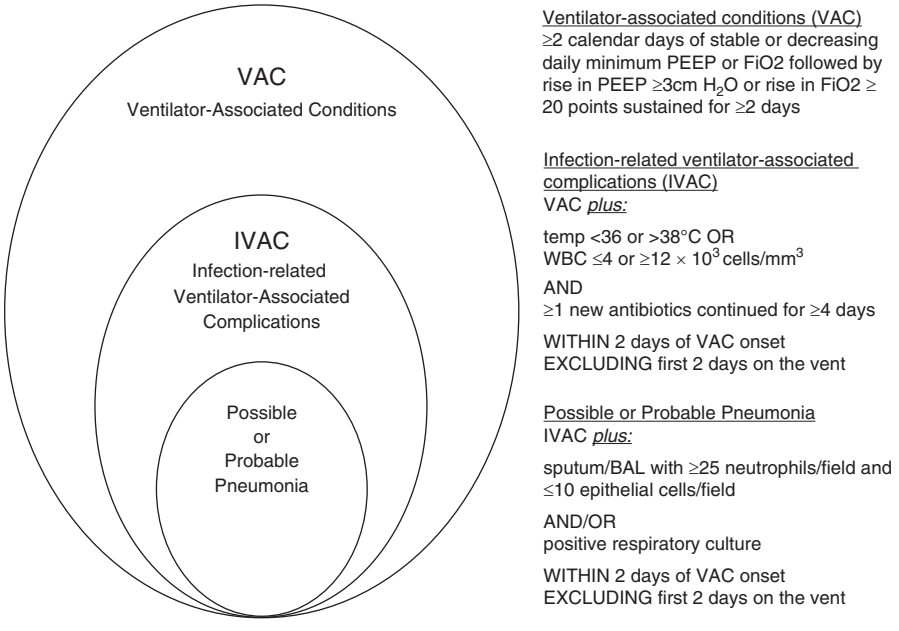

Figure 1. CDC's ventilator-associated events framework and definitions. BAL = bronchoalveolar lavage; PEEP = positive end-expiratory pressure; WBC = white blood cell count.

differences between the units that elected to join the collaborative and those that did not (*see* the online supplement).

Intervention

We developed a consensus protocol for paired daily SATs and SBTs modeled after the work of Girard and colleagues (*see* the online supplement) (8). The protocol shifted responsibility for initiating SATs and SBTs from physicians to nurses and respiratory therapists using an opt-out model. Nurses and respiratory therapists screened all patients daily for eligibility for SATs and SBTs, and when appropriate, initiated one or both interventions. SATs entailed completely stopping all sedatives and, in patients without active pain, all narcotics. If a patient passed the SAT, the protocol encouraged keeping the patient off sedatives and/or narcotics; if a patient failed the SAT then sedatives and/or narcotics were restarted at half the preceding dose. SBTs entailed lowering positive end-expiratory pressure to less than or equal to 5–8 cm H_2O with either continuous positive airway pressure or pressure support ventilation of less than or equal to 5 cm H_2O for up to 2 hours. The protocol encouraged promptly extubating patients who passed SBTs. If the SBT was unsuccessful, therapists returned patients to their prior ventilator settings. Nurses and respiratory therapists were encouraged to coordinate efforts to perform SBTs off sedatives. Each hospital's Institutional Review Board approved the study. The protocol was deemed quality improvement and therefore did not require informed consent.

The CDC Prevention Epicenters' Wake Up and Breathe Collaborative

We organized a quality improvement collaborative for the 12 intervention units using the Institute for Healthcare Improvement's All Teach All Learn framework (13). Each participating unit designated a physician, nurse, and respiratory therapist to serve as clinical champions and collaborative liaisons. We held an in-person kick-off meeting for champions at the CDC on April 24, 2012 to engage participants, review the consensus protocol, set unit-specific goals, and begin planning interventions. We taught Plan-Do-Study-Act cycles to encourage rapid prototyping of small tests of change. Clinical champions completed monthly reports detailing successes and challenges from the preceding month and setting goals for the coming month. We held monthly web conferences to review progress, share successes, and discuss challenges. We created a listserv to facilitate discussion between monthly meetings. We shared detailed performance data with each unit each month. We provided deidentified comparative statistics to allow units to compare themselves with peers. We held a second in-person meeting on October 30, 2012 to review progress, consolidate gains, and set further goals. Representatives from collaborative units helped develop the protocol and sought local approval in the months before the official kick-off of the care improvement collaborative.

We encouraged frontline clinicians to integrate documentation of SAT and SBT screenings and outcomes into existing processes, such as paper or electronic flow charts, daily ventilator bundle audits, and/or daily plan sheets. Research assistants collected basic demographic and clinical data for every patient ventilated for more than 1 calendar day including age, sex, unit, location of intubation, reason for intubation, initial Sequential Organ Failure Assessment (SOFA) score, admission and discharge dates, and vital status on discharge. They also documented daily minimum positive end-expiratory pressure, daily minimum fraction of inspired oxygen, temperature, and white blood cell count. Antibiotic exposures, pulmonary Gram stains, and culture results were collected on the subset of patients that met criteria for VAC. These data were all entered into a centralized data repository using a secure, web-based interface. Units provided ICD9 and DRG codes for each patient at the end of the study; we used these to derive comorbidities using the Elixhauser method (14, 15). Data collection for most variables began in November 2011 and continued through May 2013. Data collection for SAT performance rates began in January 2012 and continued through May 2013.

The primary outcome of the study was VAE risk per episode of mechanical ventilation (this is synonymous with the VAC risk per episode). We selected episodes rather than ventilator days as the denominator because the study intervention specifically aimed to reduce ventilator days; a disproportionate decrease in ventilator days relative to VAEs could create a misleading impression of static or increasing VAE rates. We did a secondary analysis of VAE risk per ventilator day for purposes of comparison, however, because infection control programs have traditionally used ventilator days as their denominator. Additional secondary outcomes included IVAC, possible and probable pneumonia, mean duration of mechanical ventilation, intensive care length-of-stay, hospital length-of-stay, hospital mortality, self-extubations, and reintubations within 24 hours. VAEs and episodes of mechanical ventilation were defined using CDC criteria and identified electronically using computer algorithms applied to manually collected data (16). The CDC defines an episode of mechanical ventilation as continual exposure to a ventilator for at least some part of consecutive calendar days; if a patient is disconnected from a ventilator for more than 1 calendar day then any subsequent mechanical ventilation is defined as a new episode.

Analysis

We assessed for cumulative changes across time in VAE risk, SAT and SBT rates, and other outcomes on a per-episode basis, using generalized mixed effects models to account for within-unit correlations. We used the Bernoulli distribution for binary outcomes and negative binomial distributions for counts. We originally intended to incorporate an inflection point corresponding to the collaborative kick-off meeting at the CDC on April 24, 2012. Inspection of the data, however, revealed substantial and significant increases in SAT, SBT, and proportion of SBTs performed with sedatives off in the months before the kick-off meeting (Figure 2), presumably attributable to unit champions' participation in developing the protocol and garnering local support before the kick-off meeting. We therefore elected to fit linear trends for all outcomes across the entire study period without an inflection point. We adjusted each model for patient-level age, sex, reason for intubation, SOFA score, and Elixhauser index whenever possible. We used multiple imputation with chained equations to estimate missing SOFA covariates for individuals with incomplete baseline data (e.g., bilirubin not measured) (17, 18).

We created additional models to assess the relationship between monthly unit-level SAT and SBT performance rates (predictors) and VAE risk, duration of mechanical ventilation, length-of-stay, and mortality (outcomes). We used logistic or negative binomial generalized mixed effect regression models as appropriate and adjusted for the same patient-level covariates as in our primary analysis. All analyses were executed using SAS v9.3 (SAS Institute, Cary, NC).

Role of the Funding Source

CDC scientists participated in the design, conduct, and interpretation of the study and helped edit the final manuscript.

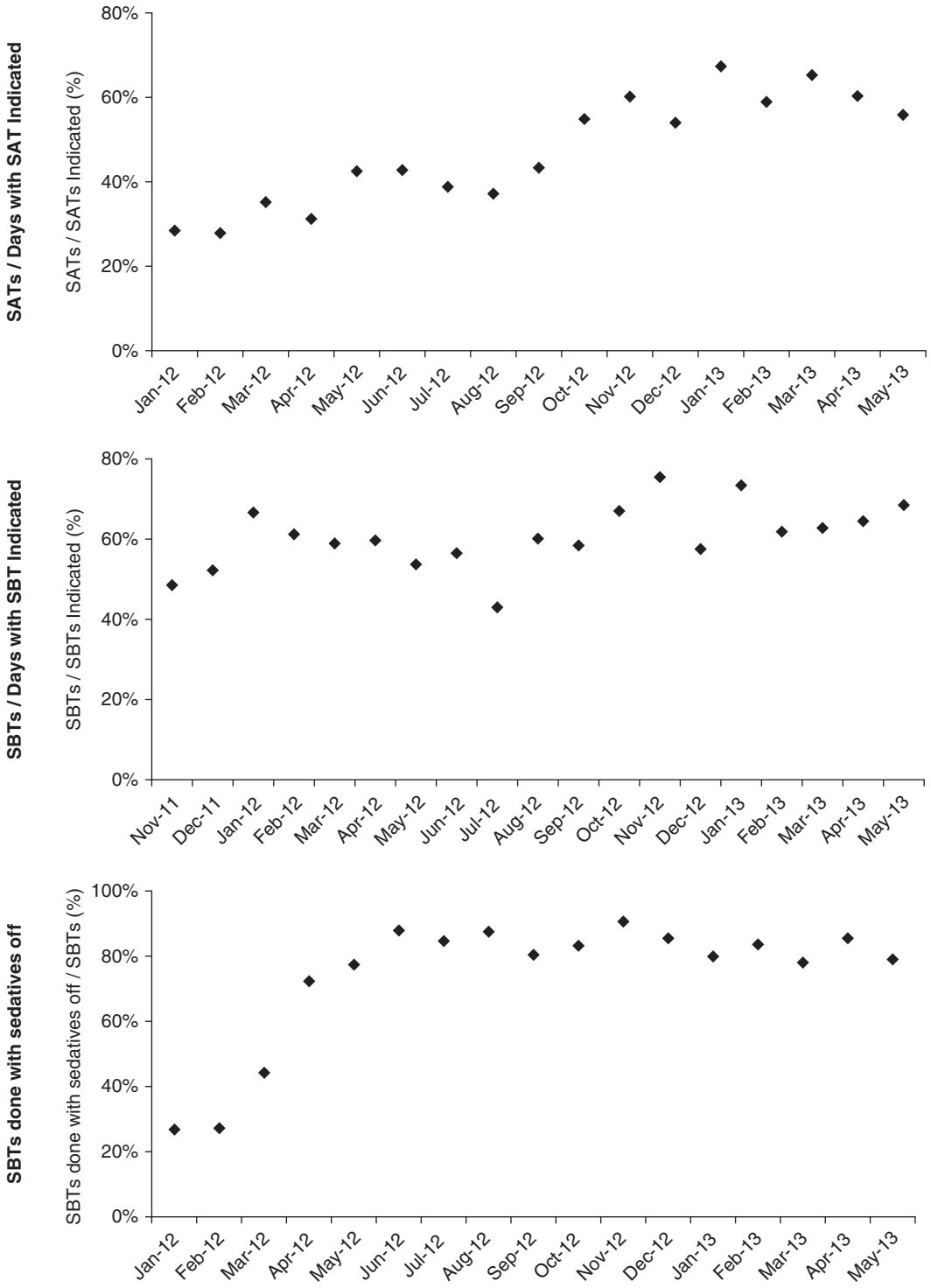

Figure 2. Spontaneous awakening trial (SAT) and spontaneous breathing trial (SBT) performance rates among collaborative units.

Results

The collaborative included four medical, two surgical, two cardiac, and four mixed medical-surgical units affiliated with seven hospitals. Collaborative units provided care for 3,425 consecutive episodes of mechanical ventilation during the study period. Patients' characteristics by episode of mechanical ventilation are summarized in Table 1. Surveillance-only ICUs included one surgical, two cardiac, and five mixed medical-surgical units affiliated with six hospitals. Surveillance-only units provided care for 1,739 consecutive episodes of mechanical ventilation.

Table 1. Patient Characteristics by Episode among the 12 Intensive Care Units Participating in the CDC Epicenters' Wake Up and Breathe Collaborative

	Collaborative Units (n = 3,425 Episodes)
Mean age (SD)	62.8 (37)
Male	1,942 (57%)
Mean SOFA score (SD)*	9.3 (3.7)
Comorbidities	
Congestive heart failure	793 (23%)
Chronic lung disease	1,037 (30%)
Diabetes	1,117 (33%)
Kidney disease	883 (26%)
Liver disease	297 (8.6%)
Cancer	430 (13%)
Peripheral vascular disease	502 (15%)
Location of intubation	
Prehospital emergency medical services	101 (2.9%)
Emergency department	595 (17%)
General medicine ward	146 (4.3%)
Operating room or recovery room	625 (18%)
Intensive care unit	1,286 (38%)
Outside facility	435 (13%)
Other	237 (6.9%)
Reason for intubation	
Altered level of consciousness	379 (11%)
Obstructive lung disease	150 (4.4%)
Cardiac arrest	256 (7.5%)
Community-acquired pneumonia	173 (5.1%)
Hospital-acquired pneumonia	94 (2.7%)
Pulmonary edema	79 (2.3%)
Sepsis	157 (4.6%)
Surgery	675 (20%)
Respiratory distress of unknown etiology	1,462 (43%)
Intensive care unit type	
Medical, four units	1,047 (31%)
Surgical, two units	358 (10%)
Cardiac, two units	343 (10%)
Mixed, four units	1,677 (49%)
Days of mechanical ventilation	
Total	22,991
Mean (SD)	6.7 (9.2)
Median (IQR)	4 (3–8)
Intensive care length-of-stay in days	
Mean (SD)	11 (14)
Median (IQR)	8 (5–14)
Hospital length-of-stay in days	
Mean (SD)	22 (25)
Median (IQR)	15 (8–26)
Hospital mortality	958 (28%)
Ventilator-associated events	
VAC†	293 (8.5%)
IVAC†	100 (2.9%)
Possible pneumonia	33 (1.0%)
Probable pneumonia	17 (0.5%)
Possible or probable pneumonia	50 (1.5%)

Definition of abbreviations: IQR = interquartile range; IVAC = infection-related ventilator-associated complications; SOFA = Sequential Organ Failure Assessment; VAC = ventilator-associated conditions.
*All 12 variables necessary to calculate SOFA scores were available for 74.4% of episodes. One of the 12 variables was missing for 24.4% of episodes, two variables were missing for 3.0% of episodes, and three variables were missing for 0.7% of episodes. We used multiple imputation to estimate values for missing variables.
†Includes episodes that meet criteria for IVAC and possible or probable pneumonia.

Collaborative units significantly increased their frequencies of SATs, SBTs, and percentage of SBTs performed off sedatives (Table 2, Figure 2). SAT performance rates increased from 14% of days where indicated to 77% of days where indicated, corresponding to an increase from 5% of ventilator days to 21% of ventilator days (mean increase, 0.9%/mo; 95% confidence interval [CI], 0.7–1.1%). SBT performance rates increased from 49 to 75% of days where indicated, corresponding to 37% of ventilator days in the first month of the collaborative and 35% of ventilator days in the last month of the collaborative. The percentage of SBTs performed with sedatives off increased from 6.1 to 87% of SBTs (mean increase, 4.8%/mo; 95% CI, 4.6–4.9%).

Improvements in SAT and SBT performance rates were paralleled by significant decreases in VAE rates (Figure 3). The VAE rate (this is synonymous with the total VAC rate) went from 9.7 events per 100 episodes of mechanical ventilation in November 2011 to 5.2 events per 100 episodes in May 2013 (adjusted odds ratio [OR], 0.63; 95% CI, 0.42–0.97). The IVAC rate dropped from 3.5 to 0.52 events per 100 episodes (adjusted OR, 0.35; 95% CI, 0.17–0.71). The possible or probable pneumonia rate decreased from 0.88 to 0.52 per 100 episodes; however, this change was not statistically significant (adjusted OR, 0.51; 95% CI, 0.19–1.3). There was no change in VAE/VAC or IVAC risk when using ventilator days rather than episodes as the denominator (*see* Table E1 in the online supplement).

Decreases in VAE risk per episode of mechanical ventilation were similar when limiting the analysis to patients ventilated for greater than or equal to 4 days (adjusted OR for VAC, 0.71, 95% CI, 0.46–1.09; adjusted OR for IVAC, 0.36; 95% CI, 0.18–0.73; adjusted OR for pneumonia, 0.56, 95% CI, 0.21–1.48). There was no significant change over time in the monthly fraction of patients ventilated for less than 4 days.

Collaborative units observed improvements in other outcomes (Figure 4). Mean duration of mechanical ventilation dropped by 2.4 days (95% CI, 1.7–3.1 d), ICU length-of-stay by 3.0 days (95% CI, 1.6–4.3 d), and hospital length-of-stay by 6.3 days (95% CI, 4.0–8.6 d). There was no change in hospital mortality (OR, 1.1; 95% CI, 0.81–1.4). There was a significant increase in self-extubations per episode of mechanical ventilation (OR, 2.1; 95% CI, 1.1–3.9) but no change in reintubations within 24 hours (OR, 0.96; 95% CI, 0.66–1.4) as depicted in

Table 2. Changes in SAT and SBT Performance Rates among Collaborative Participants between November 2011 and May 2013

Outcome	First Month* (95% CI)	Last Month* (95% CI)	Average Change per Month (95% CI)	Cumulative Change (95% CI)	*P* Value
SATs performed as percent of days with SATs indicated	14% (7.1 to 26)	77% (61 to 87)	+3.6% (3.3 to 4.0)	+63% (57 to 69)	<0.0001
SATs performed as a percent of ventilator days	5.1% (3.5 to 7.5)	21% (16 to 27)	+0.9% (0.7 to 1.2)	+16% (11 to 20)	<0.0001
SBTs performed as percent of days with SBTs indicated	49% (35 to 63)	75% (64 to 84)	+1.4% (1.0 to 1.8)	+26% (19 to 34)	<0.0001
SBTs performed as percent of ventilator days	37% (31 to 43)	35% (30 to 41)	−0.08% (−0.010 to 0.05)	−1.5% (−2.0 to −0.9)	<0.0001
SBTs performed with sedatives off as percent of all SBTs	6.1% (3.9 to 9.4)	87% (81 to 92)	+4.8% (4.6 to 4.9)	+81% (79 to 84)	<0.0001

Definition of abbreviations: CI = confidence interval; SAT = spontaneous awakening trial; SBT = spontaneous breathing trial.
*First month with available data was November 2011 for SBTs and January 2012 for SATs. Last month was May 2013.

Figure E1. There was also no change in the frequency of reintubations within 2–7 days (data not shown).

On subgroup analysis, effect estimates were broadly similar for all unit types for all outcomes, although CIs were wide and sometimes no longer significant (*see* Table E2). Improvements were seen in six of the seven hospitals and 8 of the 12 units participating in the collaborative.

The VAE rate in December 2011 was strikingly high compared with all other months. On sensitivity analysis excluding this month, the decrease in VAC was no longer significant (adjusted OR, 0.76; 95% CI, 0.49–1.20) but the decrease in IVAC persisted (adjusted OR, 0.42; 95% CI, 0.20–0.90).

There were significant associations between monthly, unit-level SAT and SBT performance rates and length-of-stay, mortality, and VAEs (Table 3). Higher SAT performance rates were associated with significantly fewer VACs (OR, 0.20; 95% CI, 0.06–0.64), IVACs (OR, 0.04; 95% CI, 0.005–0.32), possible or probable pneumonias (OR, 0.03; 95% CI, 0.003–0.40), ventilator days (OR, 0.32; 95% CI, 0.25–0.43), ICU days (OR, 0.51; 95% CI, 0.40–0.66), hospital days (OR, 0.44; 95% CI, 0.34–0.57), and lower hospital mortality rates (OR, 0.32; 95% CI, 0.14–0.74). Monthly unit-level SBT performance rates were significantly associated with fewer VACs (OR, 0.15; 95% CI, 0.06–0.38) and ventilator days (OR, 0.79; 95% CI, 0.63–0.99). The percentage of SBTs performed off sedatives was associated with fewer ventilator days (OR, 0.89; 95% CI, 0.80–0.99) and hospital days (OR, 0.82; 95% CI, 0.74–0.91) but did not correlate with VAE rates.

Among surveillance-only units, there was no significant change in SAT performance rates (9.1% of ventilator days in the first month vs. 11% of ventilator days in the last month; mean increase 0.1%/mo; 95% CI, −0.1 to +0.3%). There was a modest increase in SBT performance rates (from 22% to 24% of ventilator days; mean increase, 0.1%/mo; 95% CI, +0.03 to +0.2%) and a modest increase in the percentage of SBTs performed without sedation (from 39% to 67%; mean increase, 1.6%/mo; 95% CI, 1.3–1.9%). There was no change, however, in the overall risk of VAEs, IVAC, or possible and probable pneumonias. Clinical characteristics, SAT and SBT performance rates, and outcomes for patients in the surveillance-only units are provided in Tables E3–E5.

Discussion

The CDC developed VAE definitions to replace VAP as a possible quality measure for ventilated patients. Multiple studies have shown that VAEs strongly predict poor outcomes (19–26). Until now, however, there has been little evidence that VAEs are preventable. Our study suggests that increasing the frequency of paired, daily SATs and SBTs can significantly lower VAE rates. These gains were further associated with shorter ventilator, ICU, and hospital stays.

Our findings are concordant with evolving critical care practice standards. The Society of Critical Care Medicine's Pain, Analgesia, and Delirium Guidelines encourage minimizing sedation and early extubation (27). We show that in addition to decreasing duration of mechanical ventilation and length-of-stay, these interventions can also lower VAE rates. VAE surveillance may therefore be a useful metric to help hospitals to monitor the impact of their efforts to improve sedation and extubation practices.

We were able to significantly increase SAT and SBT rates in collaborative units despite the fact that all participants already had policies encouraging daily SATs and/or SBTs in place before joining the collaborative. National and statewide surveys affirm that SAT and SBT performance rates are often low despite policies encouraging their performance (28–31). This underscores the fact that there can often be substantial mismatch between official policies and actual performance rates. We attribute the collaborative units' increases in SAT and SBT performance to three factors: (*1*) rigorously measuring and reporting actual performance, (*2*) continually feeding back local and comparative performance rates, and (*3*) working assiduously to change providers' perceptions about sedation. Collaborative discussions were often dedicated to challenging assumptions about required levels of sedations, encouraging providers to attempt SATs and SBTs on a broader array of patients, and exploring alternative strategies to calm patients without administering additional sedatives.

The decrease in VAE risk per episode of mechanical ventilation but not per ventilator day suggests that the primary mechanism of the intervention was reducing total duration of exposure to mechanical ventilation rather than decreasing risk of

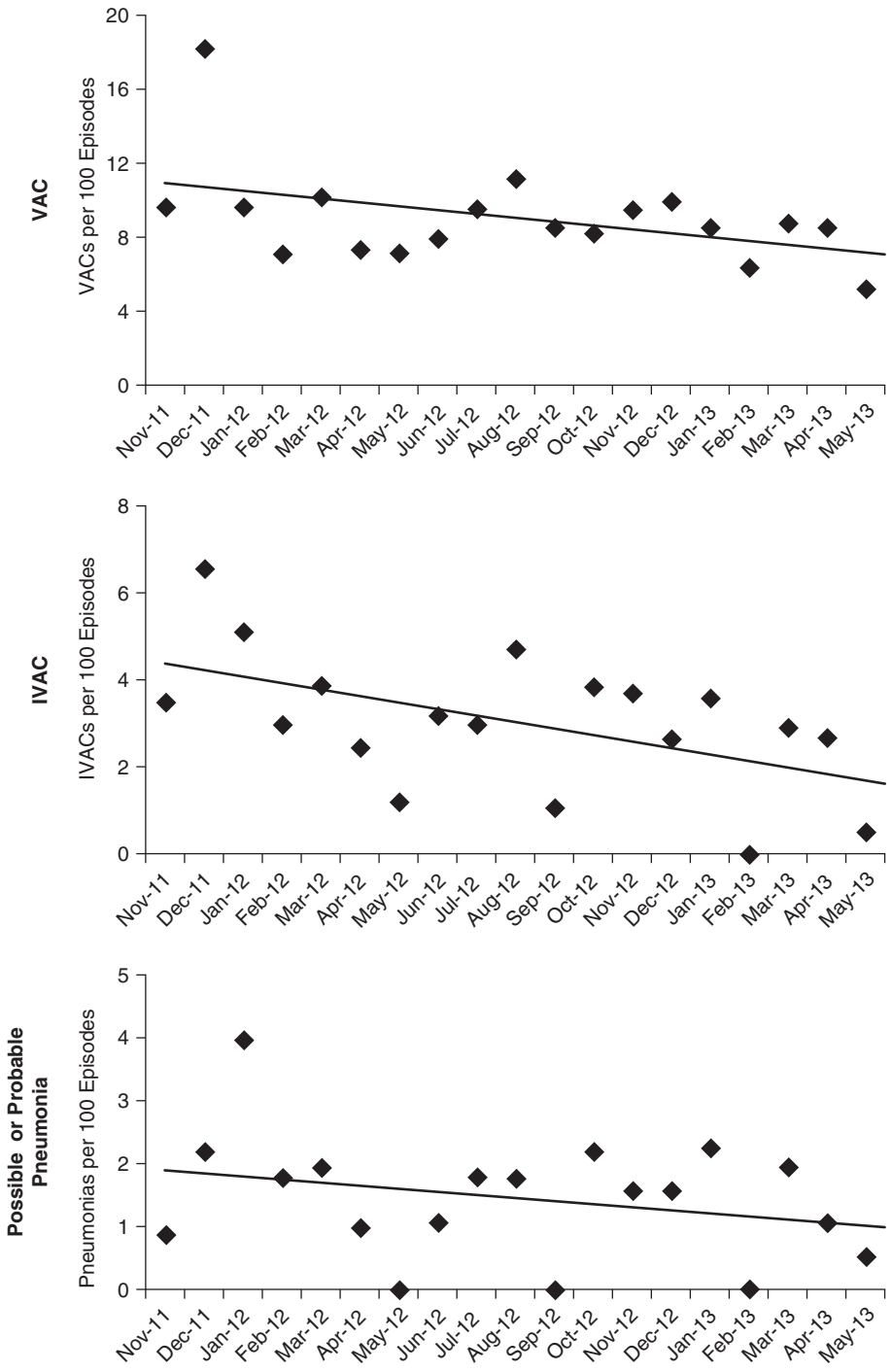

Figure 3. Changes in ventilator-associated event rates among collaborative units. Cumulative change in risk per episode derived from generalized mixed-effect regression models adjusted for age, sex, unit, reason for intubation, Sequential Organ Failure Assessment score, and Elixhauser index: odds ratio (OR), 0.63 (95% confidence interval [CI], 0.42–0.91; $P = 0.04$) (*top panel*); OR, 0.35 (95% CI, 0.17–0.71; $P = 0.01$) (*middle panel*); and OR, 0.51 (95% CI, 0.19–1.3; $P = 0.18$) (*bottom panel*). IVAC = infection-related ventilator-associated complications; VAC = ventilator-associated conditions.

complications on any given day of mechanical ventilation. Reducing duration of mechanical ventilation can lower VAE rates in two ways: by decreasing time at risk for complications and by increasing the fraction of patients ventilated for less than 4 days (because VAE criteria are only applicable to patients ventilated for ⩾4 d). On subgroup analysis, we found that the intervention decreased VAE rates among patients ventilated for greater than or equal to 4 days and there was no significant change in the fraction of patients ventilated for less than 4 days. This suggests that additional strategies to speed liberation from mechanical ventilation, such as sedation protocols, automated weaning algorithms, early mobility, and conservative fluid management, may also lower VAE rates (32–35).

These observations beg the question of whether surveillance for VAEs adds anything over surveillance for mean duration of mechanical ventilation alone. Duration of mechanical ventilation is attractive insofar as it is simple, ubiquitous, and clinically intuitive. Duration of mechanical ventilation is a very coarse metric for quality assessment, however, because it is highly dependent on case mix and does not indicate whether and when any given patient suffered a complication. VAE surveillance, by contrast, identifies a concrete complication that can serve as a focus for root cause analyses to identify possible opportunities to improve care. The evidence that most VAEs are complications includes the following: (*1*) by definition, VAEs mark trajectory changes in mechanical ventilation from stability or improvement to deterioration (4); (*2*) VAEs have been consistently associated with increased duration of mechanical ventilation and higher hospital mortality risk compared with matched control subjects (19–26); (*3*) clinical reviews of VAEs suggest that most are caused by pneumonia, hypervolemia, atelectasis, and/or ARDS (19, 21, 25); and (*4*) this study and others suggest that improvements in care can lower VAE rates (22, 36).

An insight from our study is that "episodes" might be preferable to "ventilator days" as the denominator for reporting VAE rates when the care improvement strategy is directed toward decreasing ventilator days. The large and consistent decreases in ventilator, ICU, and hospital lengths-of-stay suggest that our collaborative did improve patient care yet we only observed significant decreases in VAE rates calculated as events per episode not as events per ventilator day. This finding is consistent with

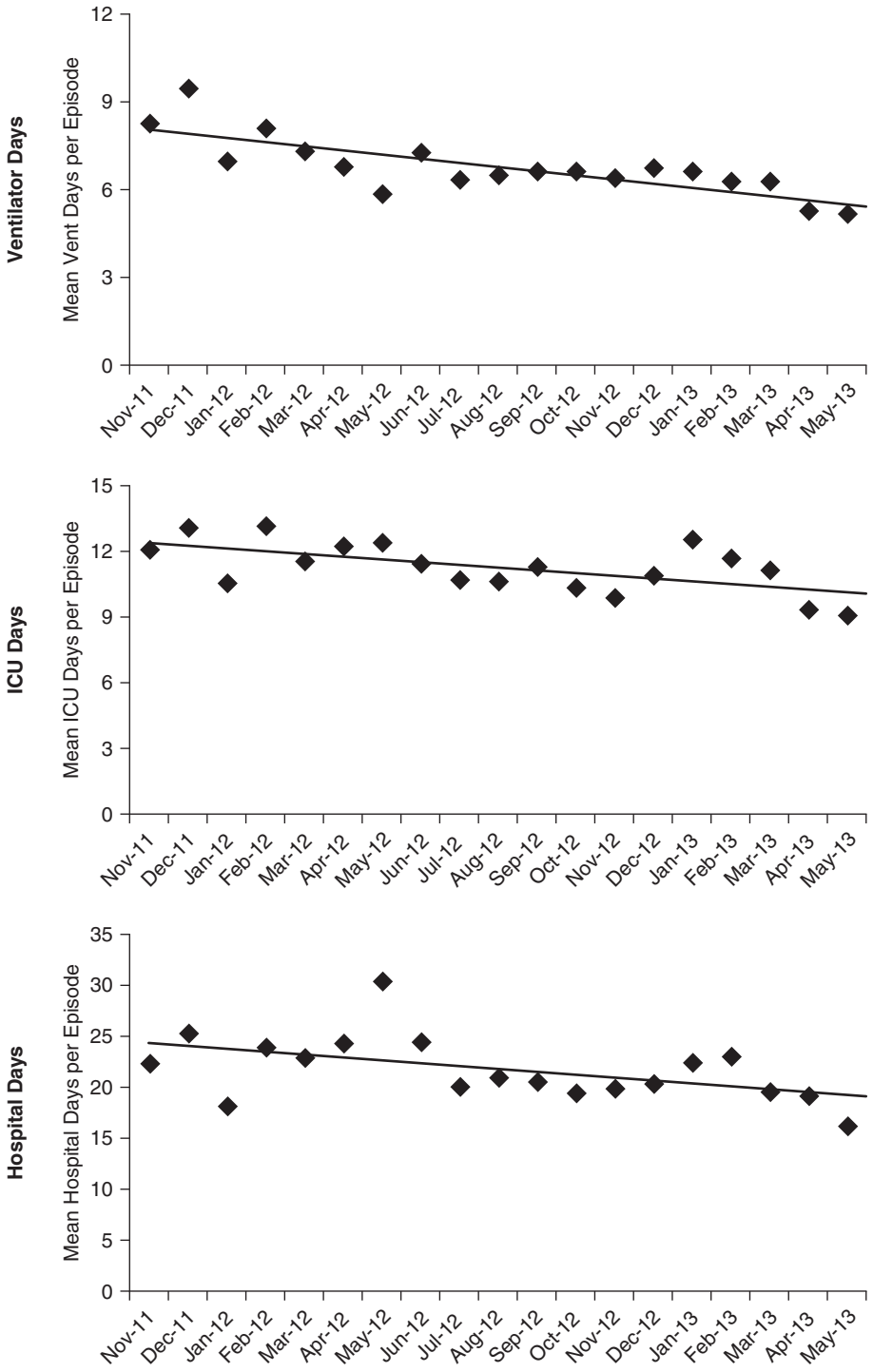

Figure 4. Changes in mean duration of mechanical ventilation, intensive care unit (ICU) length-of-stay, and hospital length-of-stay among collaborative units. Cumulative change in average days per episode derived from generalized mixed-effect regression models adjusted for age, sex, unit, reason for intubation, Sequential Organ Failure Assessment score, and Elixhauser index: −2.4 days (95% confidence interval [CI], −1.7 to −3.1; $P = 0.0001$) (*top panel*), −3.0 days (95% CI, −1.6 to −4.3; $P = 0.0001$) (*middle panel*), and −6.3 days (95% CI, −4.0 to −8.6; $P = 0.0001$) (*bottom panel*).

the literature on preventing catheter-associated urinary tract infections where interventions designed to decrease the number of catheter days can lead to paradoxical increases in infection rates expressed as the risk per catheter day (37).

Similarly, measuring SAT and SBT performance rates as a percentage of ventilator days may be more informative than measuring SAT and SBT performance rates as a percentage of "days where indicated." We observed substantial increases in SAT and SBT performance rates measured as the percentage of days where indicated but much more modest increases (or in the case of SBT, no increase) when measuring performance as the percentage of ventilator days. Reporting SAT and SBT rates as the percentage of days where indicated can be misleading because it is possible to improve the rate without necessarily changing care by assigning contraindications more liberally or by improving documentation of contraindications. Ventilator days, by contrast, are objective.

Limitations of our study include the lack of randomized control units and early adoption of the collaborative intervention before the anticipated kick-off date. It is therefore possible that the observed decreases in VAE rates were caused by preexisting secular trends or secondary to initiatives unrelated to our intervention. Our study includes five pieces of evidence that help mitigate these concerns: (*1*) analyses were adjusted using detailed patient level data including age, sex, reason for intubation, comorbidity index, and SOFA score; (*2*) a multivariable analysis affirmed the strong protective association between SATs and VAEs and other outcomes; (*3*) parallel data from units outside the collaborative showed no changes in VAE rates; (*4*) VAEs were identified objectively using electronic data; and (*5*) surveys of units before and after the collaborative did not reveal any new quality improvement interventions. Furthermore, even if the decrease in VAE rates was caused by something other than the collaborative intervention, the primary goal of this study was to assess the preventability of VAEs rather than to test the effectiveness of SATs and SBTs *per se*. The observed decrease in VAE rates suggests VAE rates can be lowered.

In summary, we demonstrate that better performance of coordinated daily

Table 3. Multivariable Analysis of the Association between Unit-Level Monthly Performance Measures and Outcomes*

	Monthly Unit Level SAT Rate Odds Ratio/ Relative Risk (95% CI)	*P* Value	Monthly Unit Level SBT Rate Odds Ratio/ Relative Risk (95% CI)	*P* Value	Monthly Unit Level SBTs Done with Sedatives Off Odds Ratio/Relative Risk (95% CI)	*P* Value
Ventilator-associated events						
Ventilator-associated conditions	0.20 (0.06–0.64)	0.007	0.15 (0.06–0.38)	<0.001	1.1 (0.68–1.8)	0.71
Infection-related ventilator-associated complications	0.04 (0.005–0.32)	0.003	0.35 (0.08–1.61)	0.18	1.2 (0.55–2.5)	0.68
Possible or probable pneumonias	0.03 (0.003–0.40)	0.007	0.24 (0.03–1.92)	0.18	1.2 (0.4–3.5)	0.73
Lengths of stay and mortality						
Duration of mechanical ventilation, d	0.32 (0.25–0.43)	<0.0001	0.79 (0.63–0.99)	0.05	0.89 (0.80–0.99)	0.03
Intensive care length-of-stay, d	0.51 (0.40–0.66)	<0.0001	1.01 (0.81–1.3)	0.92	0.91 (0.82–1.0)	0.06
Hospital length-of-stay, d	0.44 (0.34–0.57)	<0.0001	1.04 (0.8–1.3)	0.77	0.82 (0.74–0.91)	<0.0001
Hospital mortality	0.32 (0.14–0.74)	0.008	1.1 (0.60–1.9)	0.81	0.85 (0.62–1.2)	0.31

Definition of abbreviations: CI = confidence interval; SAT = spontaneous awakening trial; SBT = spontaneous breathing trial.
Analyses adjusted for patient level indicators including unit, age, sex, reason for intubation, and Sequential Organ Failure Assessment score. Monthly SAT and SBT rates calculated as number of SATs or SBTs performed divided by total ventilator days.
*Estimates for dichotomous outcomes derived from binomial distributions and presented as odds ratios; estimates for continuous outcomes derived from negative binomial distributions and presented as relative risks.

SATs and SBTs can decrease VAE rates and improve patients' outcomes. Future studies should explore whether additional interventions targeting the conditions most frequently associated with VAEs can decrease VAE rates further. The conditions most commonly associated with VAEs include pneumonia, pulmonary edema, atelectasis, and ARDS (19, 21, 25). Potential interventions could therefore include head-of-bed elevation, early mobility, low tidal volume ventilation, conservative fluid management, and conservative transfusion thresholds (33, 36, 38–40). Combining these interventions into a new ventilator bundle and using VAE surveillance to track the bundle's impact has further potential to improve outcomes for ventilated patients. ■

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