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Impact of the ventilator bundle on ventilator-associated pneumonia in intensive care unit

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Abstract

Objectives. The ventilator bundle is being promoted to prevent adverse events in ventilated patients including ventilator-associated pneumonia (VAP). We aimed to: (i) examine adoption of the ventilator bundle elements; (ii) determine effectiveness of individual elements and setting characteristics in reducing VAP; (iii) determine effectiveness of two infection-specific elements on reducing VAP; and, (iv) assess crossover effects of complying with VAP elements on central line-associated bloodstream infections.

Design. Cross-sectional survey.

Setting. Four hundred and fifteen ICUs from 250 US hospitals.

Participants. Managers/directors of infection prevention and control departments.

Interventions. Adoption and compliance with ventilator bundle elements.

Main Outcome Measures. VAP rates.

Results. The mean VAP rate was 2.7/1000 ventilator days. Two-thirds ($n = 284$) reported presence of the full ventilator bundle policy. However, only 66% ($n = 188/284$) monitored implementation; of those, 39% ($n = 73/188$) reported high compliance. Only when an intensive care unit (ICU) had a policy, monitored compliance and achieved high compliance were VAP rates lower. Compliance with individual elements or just one of two infection-related element had no impact on VAP ($\beta = -0.79$, $P = 0.15$). There was an association between complying with two infection elements and lower rates ($\beta = -1.81$, $P < 0.01$). There were no crossover effects. Presence of a full-time hospital epidemiologist (HE) was significantly associated with lower VAP rates ($\beta = -3.62$, $P < 0.01$).

Conclusions. The ventilator bundle was frequently present but not well implemented. Individual elements did not appear effective; strict compliance with infection elements was needed. Efforts to prevent VAP may be successful in settings of high levels of compliance with all infection-specific elements and in settings with full-time HEs.

Keywords: ventilator-associated pneumonia, healthcare-associated infections, infection control, ventilator bundle, intensive care units, quality improvement, guidelines

Introduction

Healthcare-associated infections (HAI) are an important patient safety concern around the globe. Ventilator-associated pneumonia (VAP) is the leading cause of death among HAI, with attributable mortality ranging from 15 to 70% depending on the patient population [1]. Moreover, the attributable cost of one VAP is estimated to exceed $22 000 [1, 2].

The Institute for Healthcare Improvement (IHI) promotes use of the ventilator bundle as a set of interventions intended to prevent adverse events in ventilated patients [3]. The ventilator bundle consists of elevation of the head of bed, daily 'sedation vacation' and assessment of readiness to extubate, prevention of stomach ulcers and deep venous thrombosis (DVT) prophylaxis [4]. Only two of the four components are intended to prevent VAP, the other two being geared toward preventing other complications of mechanical ventilation, namely DVTs and stress ulcers. Although there is widespread promotion of the ventilator bundle as a way to improve care of ventilated patients, there is limited data regarding exactly how the bundle works to prevent VAP.

Some institutions have published quasi-experimental data pointing to subsequent decreases in infection rates following bundle implementation [5–7]. In these publications, a key focus has been improving the culture of safety, and some have hypothesized that an overall heightened attention to the care of certain types of patients leads to a positive 'chain reaction' effect preventing complications; that is, making efforts to improve quality in one area should spill over into other aspects of healthcare delivery [8]. If this were the case, vigilance resulting from implementing the ventilator bundle would be associated with a crossover effect and could lead to a decrease in other types of HAI [e.g. central line-associated bloodstream infection (CLABSI) rates] in the same setting.

Finally, while reliable implementation of these bundles is clearly up to the clinicians at the bedside, the infection control department also plays a key role in the education of the staff on infection control procedures, surveillance of the infections and helping to monitor compliance with the interventions. However, there are few data regarding how the structure of infection control departments affects implementation of the bundles and resulting HAI rates.

We conducted a national survey of acute care hospital infection control programs and used the data to examine the degree to which infection control department characteristics and compliance with HAI bundles in intensive care units (ICUs) influence HAI rates. The specific aims of this study were to: (i) examine adoption of the ventilator bundle elements; (ii) determine effectiveness of individual elements and setting characteristics in reducing VAP; (iii) determine effectiveness of two infection-related elements on reducing VAP; and, (iv) assess crossover effects of complying with VAP elements on central line-associated bloodstream infections.

Methods

In Spring of 2008, a sample of hospitals belonging to the Centers for Disease Control and Prevention's (CDC) National Healthcare Safety Network (NHSN) (formerly National Nosocomial Infection Surveillance, or NNIS) was recruited. To participate in the study: (i) a hospital must have conducted NHSN device-associated surveillance of HAI in an adult medical, medical/surgical or surgical ICU in 2007 according to the module protocol; [9] and (ii) the ICU must have had a minimum of 500 device (central intravascular line or ventilator) days. There were 441 hospitals eligible to participate. While some states had mandated membership in NHSN, lists of NHSN hospitals were not public information. To protect the confidentiality of the hospitals, the CDC developed a list of eligible hospitals and e-mailed them directly to invite them to participate by accessing a web-based survey. In the communications, we asked that only one person complete the survey for their institution. The survey was designed to be answered by either a nurse or physician director or manager of the hospitals' department of infection control.

Hospital demographics of respondents were examined to check for duplicates. In the rare instances when duplicate responses were found for a single institution ($n = 31$), the surveys were examined for completeness of data and role of the respondent. Those surveys completed by directors of departments and/or those in which responses were most complete were used. All procedures were reviewed and approved by institutional review boards at Columbia University, CDC and RAND Corporation.

The development and content of the survey are described in detail elsewhere [10]. Briefly, the survey was developed building upon the questionnaire used in the Study on the Efficacy of Nosocomial Infection Control (SENIC), in which staffing of infection control programs and intensity of surveillance, prevention and control activities were first measured in US hospitals during the 1970s [11]. Respondents were asked about ICU-specific policies and practices as well as the HAI rates in eligible ICUs (i.e. an adult medical, medical/surgical or surgical ICU in which the infection prevention and control department reported to NHSN device-associated HAI surveillance in 2007).

As part of NHSN, all facilities follow specific surveillance protocols and define the presence or absence of HAI using standard CDC definitions [9]. These protocols, which include accurate case finding and HAI definitions that have both laboratory and clinical criteria, [12, 13] were developed by CDC epidemiologists and have become the recognized standard that infection control professionals around the world use [14, 15]. Previous researchers examined the sensitivity and specificity of HAI defined by these protocols compared with infections found by trained data collectors and confirmed by epidemiologists; they found the sensitivity and specificity for VAP was 68 and 98%, respectively [16].

As part of the survey, respondents were asked about four elements of the ventilator bundle: raising the head of the bed, sedation vacation, peptic ulcer and DVT prophylaxis. For each of the elements, respondents were asked the following for each of their medical, medical/surgical or surgical ICUs: (i) whether the ICU had a written policy for that bundle element, (ii) whether compliance with the policy was monitored and, (iii) the proportion of time the policy was correctly implemented. The latter was assessed using the following scale: all of the time (95–100%), usually (75–94%), sometimes (25–74%), rarely/never (<25%) and do not know. Individual ventilator bundle components were characterized based on being present and reported compliance with the policy. If the rate of compliance with policy was missing versus reported as a 'do not know', we assumed compliance to be low and set the value to rarely/never.

We also collected data on a number of other setting characteristics including the organizational structure and resources in the infection control department and other information about the hospital that has been associated with HAI rates. The infection control department characteristics assessed included staffing [i.e. presence of a full or part-time hospital epidemiologist, number of full-time equivalent positions for infection preventionists (IPs) per hospital bed and proportion of IP hours that were provided by a certified IP], the number of years that a hospital has been a member of NHSN or the NNIS system (the precursor to NHSN), and the use of an electronic surveillance system for tracking of HAIs. We further identified whether or not the hospital was located in a state with mandatory HAI reporting requirements. Other setting characteristics included hospital teaching status, number of licensed beds, hand hygiene compliance and ICU types (i.e. adult medical, surgical or medical surgical).

Table 1 Description of Hospitals and ICUs

Hospital characteristics ($n = 250$)		
Region	*n*	%
Northeast	109	44
South	66	26
Midwest	40	16
West	35	14
Mandatory reporting (State)	189	76
Bed count		
<201	50	20
201–00	145	58
501–000	50	20
>1000	5	2
Hand hygiene compliance ($n = 240$)		
All of the time (95–100%)	17	7
Usually (75–94%)	104	43
Sometimes (25–74%)	79	33
Rarely/never (<25%)	1	0.4
Hospital epidemiologist		
Full time	15	6
Part time	105	42
Years in NHSN/NNIS		
<1	33	13
1–3	78	31
<3	134	54
Missing	5	2
	Median	
Percent IP certified	50%	
Median FTE IP staffing per 100 beds		
25th percentile	0.41	
50th percentile	0.61	
75th percentile	0.87	
ICU type ($n = 415$)	*n*	%
Medical	103	25
Medical/surgical	223	54
Surgical	89	21

FTE, full-time equivalents.

Analysis

Statistics were computed to describe the sample. To assess generalizability of our sample, we compared our hospitals to all NHSN hospitals in terms of VAP rates and demographic characteristics. Then, in multivariable analyses, we examined associations between VAP rates and simply having a written policy, monitoring policy implementation and different levels of compliance. Once the needed level of compliance was established and set at 95% of the time or greater vs. other, we conducted a set of four similar multivariable analyses to elucidate the relationship between the bundle elements and VAP rates. In Model 1, we examined the independent contribution of the four bundle elements on VAP rates. In Model 2, we looked at the impact of complying with either one of the two VAP-specific bundle elements on reducing VAP rates versus compliance with neither of these elements. Model 3 assessed whether compliance with both of the two VAP-specific bundle elements was necessary to see a significant reduction in VAP rates. Next, we examined whether compliance with the two VAP-specific bundle elements was associated with lower CLABSI rates (Model 4). Finally, we estimated the change in VAP rates that would be predicted if an ICU went from no ventilator bundle implementation to full bundle compliance.

All models were multivariable ordinary least squares (OLS) regressions with Huber-White standard errors to account for intra-hospital correlations across ICU. In all analyses, indicators for the setting and infection control department characteristics previously described were included.

Results

Overall, 250 hospitals (57% response rate) with 415 ICUs participated. Table 1 presents hospital and ICU descriptive information. The majority of hospitals were located in states with mandatory reporting of HAI ($n = 189$, 76%). Only 6% of respondents ($n = 15$) reported presence of a full-time physician hospital epidemiologist; 42% ($n = 105$) reported a part-time epidemiologist. The majority of hospitals ($n = 134$, 54%) had belonged to NHSN/NNIS for >3 years. The overall mean VAP rate for 279 ICUs was 2·67 per 1000 ventilator days. As shown in Table 2, included study ICUs were similar to the full cohort of all NHSN ICUs in terms of VAP rates.

Data on adoption of ventilator bundle are shown in Table 3. While 68% of ICUs ($n = 284$) had a written policy regarding all elements of the ventilator bundle, only 66% of those ICUs monitored their implementation ($n = 188$) and of those, only 39% ($n = 73$) reported full bundle compliance defined as 95% of the time or greater.

We found no significant associations between VAP rates and having a policy, monitoring compliance or low compliance with bundle elements (data not shown). Only when an

Table 2 Comparison of VAP rates in study ICUs to all NHSN ICUs

	Study sample			NHSN[a]		
	n	Pooled mean (SD)	Median	*n*	Pooled mean	Median
Type of ICU						
Medical ICU	62	2.5 (5.0)	1	93	2.5	1.9
Medical/surgical teaching	99	2.3 (3.2)	1.2	79	3.3	2.3
Medical/surgical other	61	1.5 (2.4)	0	187	2.3	1.5
Surgical	57	4.6 (5.4)	3	87	5.3	4.5

[a]NHSN data previously published in Edwards *et al.* [27].

Table 3 Extent to which ICUs have written policies, monitor implementation and proportion of time bundle elements are correctly implemented

	Presence of written policy		Presence of monitoring for implementation		ICUs reporting correct implementation 95% of the time or greater	
	n	%	*n*	%	*n*	%
All ventilator bundle elements	284	68	188/284	66	73/188	39
Raise head of bed	372	90	290/372	78	139/290	48
Sedation vacation	337	81	249/337	74	119/249	48
Prevention of stomach ulcers	309	74	210/309	68	129/210	61
DVT prophylaxis	327	79	223/327	68	130/223	58

ICU had a policy, monitored compliance and had 95% or greater compliance was the VAP rate significantly lower. Therefore, in the multivariable analyses we examined the association between 95% or greater compliance and infection rates. In these models, no hospital characteristics had a significant impact on VAP rates. Of the infection control department characteristics examined, only the presence of a full-time hospital epidemiologist was significantly associated with lower VAP rates ($\beta = -3.62$, $P < 0.01$). This finding was robust and significant in all models.

Table 4 presents the results of the multivariate models. In Model 1, compliance with all VAP bundle elements trended towards an inverse association with VAP rates except DVT prophylaxis. However, controlling for the other elements, no individual element had a significant impact on rates. In Model 2, complying with either one of the two VAP-specific elements (sedation vacation or raising head) was also not significantly associated with lower VAP rates ($\beta = -0.79$, $P = 0.15$). However, in Model 3, there was a strong association between complying with both VAP-specific bundle elements and lower VAP rates ($\beta = 1.81$, $P < 0.01$). In Model 4, there was no evidence of a crossover effect between compliance with the two VAP-related elements and lower CLABSI rates. Based on Model 3 results, for ICUs that complied with neither element of the VAP bundle, moving to full compliance would lower VAP rates by 58%.

Discussion

To our knowledge, our study is the first large-scale national study to examine adoption and compliance of the ventilator bundle in ICUs. We found that the ventilator bundle was frequently present but not well implemented. This is very important since we found no association between simply having a policy, monitoring implementation or less than ideal compliance and lower VAP rates. Indeed, 95% or greater compliance was needed in order to see a difference.

There is other evidence that having a policy present is insufficient and high compliance is needed. In a single ICU, Marra *et al.* [17] also found high compliance with policies was needed to see an impact on infection rates. The potential 58% decrease in VAP rates we found when moving from no compliance to full compliance is very similar to that found by Resar *et al.* [6]. In this study of a 61-hospital collaborative, the investigators found that the 21 ICUs reported 95% or greater compliance with the full bundle and in these ICUs there was a 59% decrease in VAP rates. Additionally, using our same sample, when examining the association between implementation of the central line bundle and CLABSI rates, we found very similar results in that the central line bundle was associated with lower infection rates only when hospitals had high compliance and there was no crossover effect of the central line bundle on VAP rates [18].

Table 4 Multivariate regression analyses

	Coef	SE	*P*-Value	95% CI
Model 1: Individual impact of each element on ICU VAP rates				
Raising of head	−0.66	0.79	0.41	−2.22 to 0.90
Sedation vacation	−0.88	0.84	0.30	−2.53 to 0.78
Prevention of stomach ulcers	−0.77	0.86	0.37	−2.45 to 0.91
DVT prophylaxis	0.50	0.67	0.46	−0.81 to 1.81
Model 2: Impact of complying with one of two VAP-related elements on ICU VAP rates				
One of two VAP-related elements (sedation vacation or raising head of bed)	−0.79	0.55	0.15	−1.86 to 0.29
Model 3: Impact of complying with both VAP-related bundle elements on ICU VAP rates				
Sedation vacation and raising head of bed	−1.81	0.62	<0.01	−3.02 to −0.60
Model 4: Impact of VAP-related bundle elements on ICU CLABSI rates				
Sedation vacation and raising head of bed	−0.22	0.58	0.71	−1.36 to 0.92

All models multivariate OLS regressions with Huber-White standard errors to account for intra-hospital correlations across ICUs. In all models the following covariates were controlled for: geographic region, teaching status, presence of hospital epidemiologist (full and part-time), proportion infection preventionist (IP) certified, IP staffing, use of electronic surveillance system, hand hygiene, years in National Healthcare Safety Network, bedsize and type of ICU.

The lack of a crossover effect is important. While it has been suggested that implementing bundle strategies leads to a general atmosphere of care and vigilance, we found that the impact of these bundles is quite focussed. Although it may appear obvious that a ventilator bundle prevents VAP and a central line bundle prevents CLABSI, questions have been raised about this issues. For example, Resar *et al.* [6] speculated that it is not so much the ventilator bundle itself as a 'changed delivery system' and 'chain reaction' of increased attention to the patients that led to improvements in VAP. However, our data point to a very targeted link between high compliance with the infection-specific VAP bundle elements and VAP rates. Thus, our findings suggest that to reduce VAP, infection control programs must specifically target VAP in their prevention strategies. Indeed, concentrating on the bundle elements alone may be insufficient without adequate attention to the overall organizational climate. In the original studies of the CLABSI bundle, there was a strong effort to develop teamwork and create a strong safety climate [5].

Most of the other variables we studied (e.g. hospital size, teaching status, geographic region) were not significantly associated with VAP rates, with the important exception of the presence of a full-time hospital epidemiologist. While this may be one of the first studies since the 1970s that found a statistically significant relationship between presence of a hospital epidemiologist and HAI rates these findings are very plausible [11, 18]. The implementation of policies such as sedation vacation for a ventilated patient requires substantial physician buy-in. It is likely that an actively involved full-time hospital epidemiologist may be necessary to engage and motivate the physicians providing this type of evidence-based care in an ICU.

In Models 2 and 3, we specifically examined the two bundle elements specifically related to reducing VAP. When the other two ventilator bundle elements (DVT and stress ulcer prophylaxis) were included in other models, the association was diminished (results not shown). This is not surprising given data showing that stress ulcer prophylaxis, presumably by raising gastric pH levels, is considered a risk factor for nosocomial pneumonia in both ventilated and non-ventilated patients [19, 20]. While Resar *et al.* [6] found that implementing the entire ventilator bundle led to lower VAP rates and other researchers found that individual elements of the ventilator bundle decreased VAP [21–23], the evidence establishing a relationship between implementing the full bundle and decreasing VAP is not conclusive [24]. To our knowledge no other study has assessed the effect of a combination of two elements related specifically to VAP. It is important to remember that the full ventilator bundle is intended to improve other outcomes for ventilated patients in general and that not all elements are intended to lower VAP. Indeed, only the two infection elements are recommended by NHSN to prevent VAP. For those ventilated patients most at risk for infection applying the full ventilator bundle may not represent best practice. Future research is warranted.

Our study has several limitations. Data come from a cross-sectional survey in the USA. Although we obtained a 57% response rate comparable to other surveys of healthcare professionals, [25–26] there is potential for non-response bias. To assess this, we compared VAP rates from study ICUs to published VAP rates for all NHSN ICUs [27] and found them to be similar. There is also potential for uncontrolled confounding due to variations in other unmeasured factors such as patient safety culture in each hospital. However, we believe the lack of a crossover effect minimizes this concern. If greater focus on patient safety culture led to lower VAP rates and better compliance with the VAP bundle, we would also expect to see a similar relationship between safety culture and CLABSI rates resulting in a spurious association between CLABSI rates and compliance with the VAP

Bundle. Similarly, there is potential for self-report bias in that respondents may have over-reported compliance and under-reported HAI rates. If this were the case, again we would expect hospitals to underreport both VAP and CLABSI rates and expect to see an association between compliance with the ventilator bundle and CLABSI rates. However, the lack of a crossover effect of ventilator bundle compliance on CLABSI rates was observed minimizing potential for these biases and providing evidence to the internal validity of the study. Finally, we surveyed only NHSN hospitals at a time when NHSN consisted mainly of larger, teaching hospitals. Additionally, due to our eligibility criteria of a minimum number of device days, our study hospitals were more likely to be larger than average NHSN hospitals, which may limit generalizability of results to smaller hospitals.

Use of daily oral care with chlorhexidine was added as an element to the IHI ventilator bundle in May 2010·[28]. We do not have data on this element nor do we have data on the use of other evidence-based practices [29, 30], such as the use of selective decontamination, subglottic secretion drainage or silver-sulfadiazine-coated endotracheal tubes, which is a limitation. Further research is needed to assess the impact of these elements on the prevention of VAP.

Conclusions

Findings from this study suggest that high compliance is needed to prevent VAP using the bundle strategy. Clearly, simply having a policy in place is insufficient to reduce VAP rates. Monitoring bundle compliance and implementing interventions to ensure high compliance are needed in order to see a decrease in rates. Future research is warranted.

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