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Multidisciplinary Quality Improvement Initiative to Reduce Ventilator-Associated Tracheobronchitis in the PICU

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Abstract

Objective—To test the hypothesis that successful implementation of a care bundle designed to prevent nosocomial airway infection will be associated with decreased incidence of ventilator-associated tracheobronchitis.

Design—Prospective pre- and postinterventional.

Setting—PICU at an academic medical center

Patients—All patients admitted to the PICU who received invasive mechanical ventilation for greater than or equal to 48 hours between March 1, 2009, and December 31, 2011.

Intervention—Multidisciplinary, unitwide implementation of an evidence-based care bundle to prevent ventilator-associated airway infection.

Measurements and Main Results—There were 725 patients included in the analysis (338 patients preintervention and 387 patients postintervention). Baseline ventilator-associated tracheobronchitis rate in the preintervention period was 3.9 cases per 1,000 ventilator days compared with 1.8 cases per 1,000 ventilator days postintervention ($p = 0.04$, Fisher exact test). Compared with patients without ventilator-associated tracheobronchitis or ventilator-associated pneumonia, patients with ventilator-associated tracheobronchitis had fewer ventilator-free days in 28 days (4.9 vs 22; $p < 0.0001$, Mann-Whitney U test) and fewer ICU-free days in 28 days (0.5 vs 19; $p < 0.0001$, Mann-Whitney U test). These relationships remained significant after adjusting for covariates by multivariable linear regression.

Conclusions—Successful implementation of a care bundle to prevent ventilator-associated infection was associated with decreased incidence of ventilator-associated tracheobronchitis. Development of ventilator-associated tracheobronchitis was independently associated with adverse outcomes in our cohort of pediatric ICU patients.

Keywords

infection control; nosocomial; pediatric; quality improvement; respiratory tract infections; tracheitis

Lower airway infection is among the leading causes of hospital-acquired infection in the PICU (1). Pediatric ventilator-associated pneumonia (VAP) is associated with increased ventilation days, ICU and hospital lengths of stay, and mortality (2, 3). In addition to VAP, the Centers for Disease Control and Prevention (CDC) (4, 5) have defined criteria for ventilator-associated airway infection without radiographic evidence of new pneumonia. This has been termed as “ventilator-associated tracheobronchitis” (VAT). VAT may be more prevalent than VAP in children and may be an important source of PICU morbidity (6, 7). Although quality improvement measures have been successfully employed to reduce the incidence of VAP, it is unknown whether quality-improvement measures designed to prevent VAP will also reduce the incidence of VAT.

In 2009, as a means to capture a more complete spectrum of nosocomial airway infection, our hospital began tracking VAT rates in addition to VAP rates in our PICU. By early 2010, VAT rates far exceeded VAP rates in our unit (3.9 cases per 1,000 ventilator days vs 0.3 cases per 1,000 ventilator days). In March of 2010, a multidisciplinary team was convened and tasked with creating and implementing a care bundle intended to reduce the incidence of ventilator-associated airway infection. The aim of this prospective quality improvement effort was to test the hypothesis that successful implementation of a care bundle to prevent ventilator-associated infection would reduce the incidence of VAT in PICU patients.

MATERIALS AND METHODS

Setting

The PICU at Nationwide Children’s Hospital is a 30-bed multidisciplinary, quaternary care unit with approximately 2,000 admissions annually. It is a mixed medical/surgical ICU wherein all patients are managed or comanaged by pediatric critical care physicians. Patients admitted to a separate ten-bed cardiothoracic ICU were not included in this study. Similarly, patients with tracheostomy and chronic need for mechanical ventilation who were admitted to a separate non-ICU-based unit were not included.

Care Bundle Creation and Implementation

A multidisciplinary team was convened in March 2010 to create and implement a care bundle to target VAT prevention. The team consisted of physicians, nurses, and respiratory therapists. Elements of the care bundle were adapted from previously published pediatric VAP bundles (2, 8) and can be found in Table 1. Additional interventions included identifying and reporting VAT infections in real time in order to evaluate overall bundle performance. For each case of VAT, a bedside practitioner huddle, including select PICU leadership, was convened to discuss potentially preventable causes of the infection. These improvement opportunities along with unitwide infection rates and bundle compliance graphs were posted on bulletin boards near the staff break rooms and on a liquid crystal display screen in the staff break room. The prevention bundle was deemed fully implemented when compliance with all measured bundle elements (mouth care and head of bed [HOB] elevation) reached greater than 80% (achieved in May 2010).

Although not protocolized, it is routine practice in our unit to use cuffed endotracheal tubes (ETTs) with cuffs inflated to minimal occlusive pressure and monitored every 8 hours. It is also routine practice to provide acid blockade treatment (either an H₂ blocker or proton-

pump inhibitor) to every intubated patient. Patients do not routinely receive prophylactic antibiotics. Decisions regarding antibiotic treatment of suspected VAT infections were made by the primary treatment team. As part of a pre-existing unit-based protocol, patients with suspected nosocomial infection receive a standardized antibiotic regimen of vancomycin plus an aminoglycoside plus an antipseudomonal extended-spectrum beta lactam or cephalosporin while awaiting culture results. When culture results become available, empiric antibiotics are discontinued or narrowed as deemed appropriate by the treatment team.

Data Collection and Definitions

All patients admitted to the PICU at Nationwide Children's Hospital between March 1, 2009 (14 mo preintervention), and December 31, 2011 who received invasive mechanical ventilation for greater than or equal to 48 hours were included. Cases of VAP or VAT were identified by a single individual in the hospital epidemiology department throughout the study period and defined by established CDC criteria (5). VAT criteria were assessed within 48 hours of positive culture and included the following: lack of chest radiograph findings consistent with CDC criteria for VAP (4), plus: for patients more than 1 year old at least two of the following: temperature greater than 38°C, cough, new or increased sputum production, rhonchi, or wheezing *plus* positive culture obtained by lower airway specimen. For infants less than or equal to 1 year old, at least two of temperature greater than 38°C, cough, new or increased sputum production, rhonchi, or wheezing, respiratory distress, apnea, or bradycardia (< 100 bpm) *plus* positive culture obtained by lower airway specimen. New or increased sputum production was defined by increased suctioning frequency and amount of secretions recorded on the nursing flow sheet or a change from clear or white secretions to yellow or creamy secretions. Surveillance cultures were not performed during the study period. The decision to obtain airway cultures was determined by the primary treatment team. As quantitative or semiquantitative cultures are not a part of the CDC definition for VAT, a positive culture was defined as any growth of new pathogenic bacteria from a lower airway specimen obtained more than 48 hours after intubation (or from ICU admission for patients with pre-existing tracheostomy). Cultures which grew the same organisms that were present within 48 hours of intubation were considered continuation of community-acquired infection and were not evaluated further. Daily chest radiographs are routinely performed on all endotracheally intubated patients and all patients with tracheostomies and active lung disease. VAT rates were defined as number of events per 1000 mechanical ventilator days.

Demographic information, including age, gender, severity of illness as measured by the Pediatric Risk of Mortality (PRISM) III (9) score within 12 hours of ICU admission, diagnoses, duration of mechanical ventilation, PICU and hospital lengths of stay, and mortality, were obtained from the electronic medical record or were extracted from the Virtual PICU Systems (VPS, LLC, Los Angeles, CA) database.

The study was approved by the Institutional Review Board at Nationwide Children's Hospital that granted a waiver of informed consent.

Data Analysis

The preintervention VAT rate (March 2009 to May 2010) was compared with the postintervention VAT rate (June 2010 to December 2011) by Fisher exact test. To evaluate the relationship between VAT and patient outcomes, we compared all patients with VAT during the study period (pre- and postintervention) with all PICU patients without VAT or VAP mechanically ventilated via endotracheal or tracheostomy tube for greater than or equal to 48 hours during the study period. Our primary outcome measures were ventilator-

free days in 28 days and ICU-free days in 28 days. All patients who died in the ICU had zero ICU-free days and zero ventilator-free days. Patients who received a tracheostomy during their ICU stay and were discharged on positive pressure also had zero ventilator-free days. Patients with a tracheostomy and with a baseline requirement for mechanical ventilation were excluded from the analyses of ventilator-free days. Categorical variables were compared between groups by Fisher exact test, whereas continuous variables were compared between groups by Mann-Whitney *U* test. Multivariable linear regression was used to determine independent associations between development of VAT and ventilator-free days and ICU-free days in the first 28 days after ICU admission. Variables evaluated for inclusion in the final models included age, gender, admitting diagnosis (medical vs surgical; infectious vs noninfectious; respiratory vs nonrespiratory; oncological vs nononcological), pre- versus postintervention period, and PRISM III score. Backward selection method was used to select variables for the final models, which included the presence of VAT, PRISM III score, and infectious versus noninfectious primary diagnosis. A *p* value of less than 0.05 was considered significant throughout.

RESULTS

There were 725 patients admitted to the PICU between March 1, 2009, and December 31, 2011, who received invasive mechanical ventilation for at least 48 hours. There were 338 patients admitted during the preintervention period comprising 4,815 ventilator days, and 387 patients were admitted during the postintervention period comprising 5,983 ventilator days. Demographic data, resource utilization, and VAT rates for the two time periods can be found in Table 2. Overall, baseline patient characteristics were similar between the two time periods. Although PRISM III scores were slightly higher in the preintervention period, the median values were the same. Median durations of mechanical ventilation and ICU stay were shorter postintervention.

Figure 1 outlines monthly bundle compliance rates for mouth care and HOB elevation. Mouth care documentation increased from about 75% to just less than 90% quickly with bundle implementation and achieved near 95% compliance within 6 months. Similarly, HOB elevation improved quickly with bundle implementation; however, a decrease in compliance occurred about 1 year later. This was concurrent with an increased focus by the team on other bundle components, such as suctioning the mouth before the ETT and required renewed educational efforts. These included new e-mail communications to staff members and postings on staff bulletin boards.

Overall, there were 30 cases of VAT identified. Nineteen cases were identified preintervention (3.9 cases per 1,000 ventilator days) and 11 cases of VAT (1.8 cases per 1,000 ventilator days) were postintervention (Fig. 2). There was one case of VAP in the preintervention period and zero cases of VAP postintervention. Although VAT rates quickly decreased with bundle implementation, there was a slight increase in rates noted concurrent with decreases in compliance with HOB elevation.

Table 3 outlines clinical characteristics of all VAT infections. Lower respiratory cultures were obtained by protected brush tracheal aspirate in 57% of VAT cases and by simple ETT or tracheostomy tube suctioning in the remainder. There were “many” or “moderate” polymorphonuclear cells (PMNCs) on Gram stain in 27 patients (90%). In two patients, there were no or few PMNCs, and in one patient Gram stain was not performed. Infection with a single Gram-negative species was most common (*n* = 13), with *Pseudomonas aeruginosa* predominating (*n* = 5). The only Gram-positive organism identified was *Staphylococcus aureus* (*n* = 6). Seven cases (23%) were polymicrobial. Ninety percent of patients with VAT had initial cultures obtained within 48 hours of admission, thus

permitting us to document the VAT event as a new hospital-acquired infection. In 16 cases, the initial culture was negative, and in 11 cases the VAT culture grew organism(s) that were different from initial culture. All cases of VAT were treated with parenteral antibiotics. The median duration of antibiotic therapy in patients with VAT was 7 days.

Table 4 outlines comparative demographic and patient outcomes data for patients with VAT and mechanically ventilated patients (> 48 hr) without VAT or VAP. Baseline characteristics were similar between groups. Forty-one patients (5.9%) without VAT or VAP and one patient (3.3%) with VAT had a tracheostomy tube present at admission and chronic need for positive-pressure ventilation. Patients diagnosed with VAT had significantly fewer ventilator-free days ($p < 0.0001$) and ICU-free days at 28 days ($p < 0.0001$) compared with mechanically ventilated patients without VAT or VAP. In multivariable regression analyses, the presence of VAT and higher PRISM III score were independently associated with fewer ventilator-free days ($p < 0.0001$ for both). Presence of VAT ($p < 0.0001$), higher PRISM III score ($p < 0.0001$), and noninfectious primary diagnosis ($p = 0.03$) were independently associated with fewer ICU-free days.

DISCUSSION

Implementation of a care bundle to prevent ventilator-associated airway infection was associated with a 53% reduction in the rate of VAT for over 18 months in our PICU.

To date, there have been no previously published studies of interventions to reduce VAT in children. Specific care bundles have been employed, however, to prevent VAP (2, 8). Bigham et al (2) utilized a respiratory therapist-driven VAP prevention bundle to reduce the VAP rate in a single PICU from 5.6 cases per 1,000 ventilator days to 0.3 cases per 1,000 ventilator days. The reduced rate was sustained for 2 years postintervention. Rosenthal et al studied VAP rates before and after implementation of the International Nosocomial Infection Control Consortium's infection control program in five PICUs in developing countries. Implementation of the bundle in this cohort was associated with a decrease in VAP rate from 11.7 cases per 1,000 ventilator days to 8.1 cases per 1,000 ventilator days (8).

This study utilized elements adapted from each of these two pediatric VAP prevention care bundles. In selecting which elements to include in our bundle, we strove to choose interventions that were specific, measurable, achievable, relevant, and time limited (10). These interventions were monitored in real time allowing for near immediate feedback both at the microsystem unitwide level and to individual providers. Another key aspect to our intervention was the creation of a multidisciplinary leadership team. As bedside nurses and respiratory therapists were responsible for directly implementing bundle elements, it was important to have their involvement to help identify barriers and employ successful implementation strategies. Although the overall VAT rate was significantly lower postintervention, it is notable that as compliance with the care bundle slipped in the spring of 2011, VAT rates increased. This demonstrates the importance of ongoing monitoring and feedback to achieve sustainable change.

Prior to this study, there have been limited data on outcomes related to VAT in children. A PubMed search for ventilator-associated tracheitis or VAT reveals only two studies of VAT in children (6, 7). Mhanna et al reviewed 217 pediatric trauma patients and found that development of VAT was associated with increased ICU length of stay and prolonged duration of mechanical ventilation. However, patients with VAT were those with higher injury severity at admission, and these differences were not accounted for in the analysis. Tamma et al retrospectively reviewed children with VAT comparing those treated with

antibiotics for less than 7 days to those treated with antibiotics for greater than or equal to 7 days. There was no difference between groups in their primary outcome measure, development of hospital-acquired pneumonia within 10 days of discontinuing antibiotic therapy. Other outcomes related to VAT infection were not examined.

Whether VAT represents a distinct source of morbidity or is a risk factor for progression to VAP is a topic of debate (11–14). It is interesting that in our cohort, no cases of VAP developed after VAT infection. Although we speculate that this may be due to the protocolized use of empiric broad-spectrum antibiotics, the study was not designed to evaluate antibiotic treatment of VAT. The lack of VAP in our cohort does suggest that development of VAT alone may contribute to adverse outcomes in pediatric patients in the absence of progression to VAP.

There are several limitations to our study. First, as elements of the care bundle were implemented together and concurrently with successful efforts to improve hand hygiene, we are unable to determine the individual effects of each intervention. Likewise, the small but statistically significant difference in baseline severity of illness between the pre- and postintervention groups could have contributed to the decrease in VAT rate. Nonetheless, we did show that VAT rate reduction occurred in parallel with VAT prevention bundle compliance. In addition, potentially confounding clinical practices (e.g., acid suppression, feeding practices, cuffed ETT use, and positive end-expiratory pressure use) along with extubation and ICU discharge criteria were not standardized during the study period. Though there were no formal changes in practice over the time interval, it is possible that differences in clinical practice could have contributed to our results. Also, being a single center study, our sample size was not large enough to be able to account for all potential confounders in our analyses. Finally, it should be noted that the CDC definitions, while the current gold standard in the field, are imperfect. Many of the criteria, including cough, respiratory distress, and apnea are difficult to assess in a sedated, mechanically ventilated child. Other criteria, such as change in tracheal secretions, may be subjective and difficult to quantify. Further, clinical characteristics used to define VAT may not be specific for bacterial infection. Of note, revised CDC criteria for ventilator-associated infections in adults are forthcoming, including the use of quantitative culture data (15). In the future, pediatric versions of these definitions may lessen the subjectivity currently associated with VAT diagnosis and inform subsequent studies in this field. These studies may also evaluate the role of biomarkers and other clinical characteristics that may even better define ventilator-associated infection in children.

CONCLUSIONS

Implementation of an evidence-based care bundle to prevent ventilator-associated airway infection by a multidisciplinary team with real-time feedback was associated with a reduced rate of VAT in our PICU. Development of VAT was independently associated with adverse outcomes in our cohort of PICU patients, suggesting that it may represent a clinically relevant hospital-acquired infection.

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Figure 1.
Monthly compliance with key care bundle elements. HOB = head of bed.

Figure 2. Ventilator-associated tracheobronchitis (VAT) infections per 1000 ventilator days. Vertical line = care bundle implementation period; horizontal dashed lines = VAT rates pre- and postintervention.

TABLE 1

Summary of Interventions to Reduce Ventilator-Associated Airway Infection

Pediatric Ventilator-Associated Pneumonia/Ventilator-Associated Tracheobronchitis Prevention Bundle		
Bundle Elements	Interventions	Monitoring
Elevate head of the bed to at least 30°	Staff education	Daily monitoring of HOB position with feedback to bedside provider
	Purchased cribs and warmer beds that allowed easier HOB elevation	Weekly HOB monitoring and re-enforcement during skin care rounds
Oral care with chlorhexidine rinse at least every 4 hr	Staff education	Monthly auditing of oral care documentation with unitwide feedback and feedback to individual bedside providers
	Placed oral care kits at the bedside	
	Standardized times for oral care, coordinating with other cares	
	Placed visual reminders at the bedside	
Extubate as soon as possible	Revised ventilator weaning protocol	Weekly auditing of daily goal sheets with feedback to physicians
	Added ventilator weaning to daily goal sheets	
	Respiratory therapist participated on rounds to discuss weaning goals	
Suction oral secretions before the ETT using a separate catheter for oral secretions. Use closed suctioning systems for ETT suctioning	Staff education	
Perform hand hygiene between patient contacts ^a	Increased accessibility of alcohol-based hand gel dispensers	Weekly monitoring with unit-specific feedback
	Hospital-wide dedicated meetings between all staff and managers to address barriers to hand hygiene compliance	

HOB = head of bed, ETT = endotracheal tube.

^aConcurrent hospital-wide intervention to improve infection control, not specific to ventilator-associated pneumonia/ventilator-associated tracheobronchitis prevention.

TABLE 2

Patient Demographics During Pre- and Postintervention Periods

Characteristic	Preintervention From March 2009 to May 2010 (<i>n</i> = 338)	Postintervention From June 2010 to December 2011 (<i>n</i> = 387)	<i>p</i>
Age (mo)	18.8 [3.6–109]	27.8 [5.2–144]	0.08
Female gender, <i>n</i> (%)	130 (38)	148 (38)	1
Pediatric Risk of Mortality III	6 [3–13]	6 [2–10]	0.02
Admitting diagnosis, <i>n</i> (%)			
Surgical	70 (20)	95 (25)	0.15
Respiratory	136 (40)	149 (39)	0.6
Infection	167 (49)	178 (46)	0.4
Oncological	25 (7)	23 (6)	0.5
Extracorporeal membrane oxygenation, <i>n</i> (%)	7 (2)	6 (1.6)	0.8
Duration of mechanical ventilation (d)	5.6 [3.6–10.6]	5 [3.2–8.5]	0.02
ICU length of stay (d)	9 [6.1–15.6]	7.8 [5–14.2]	0.01
Ventilator-associated tracheobronchitis rate ^a	3.9	1.8	0.04

Data are median [IQR] unless otherwise specified. *p* values less than 0.05 are marked in bold.

^aNumber of ventilator-associated tracheitis infections per 1000 ventilator days.

TABLE 3

Characteristics of Ventilator-Associated Tracheobronchitis

Characteristics	VAT (<i>n</i> = 30)
Time from ICU admission to VAT diagnosis (d)	9.6 [6–13]
Change in tracheal secretions, <i>n</i> (%)	30 (100)
$T_{\max} > 38^{\circ}\text{C}$, <i>n</i> (%)	27 (90)
Abnormal peripheral WBC count, <i>n</i> (%)	16 (53)
Increase in ventilator settings, <i>n</i> (%) ^a	13 (43)

VAT = ventilator-associated tracheobronchitis, $T_{\max}$ = maximum temperature; data are median [IQR] unless otherwise specified.

^a Increase in ventilator settings defined as increase in positive end-expiratory pressure, peak inspiratory pressure or Fio_2 by at least 10% on the day of VAT diagnosis compared with 48 hr prior.

TABLE 4

Demographic and Outcomes Data for Patients Mechanically Ventilated for Greater Than 48 Hours

Characteristic	VAT, <i>n</i> = 30	No VAT or Ventilator-Associated Pneumonia, <i>n</i> = 695	<i>p</i>
Age (mo)	55 [9.5–133]	23.7 [4–120]	0.24
Female gender, <i>n</i> (%)	12 (40)	267 (38)	0.85
Pediatric Risk of Mortality III	7 [3–15]	6 [2–11]	0.16
Admitting diagnosis, <i>n</i> (%)			
Surgical	10 (33)	146 (21)	0.11
Respiratory	12 (40)	271 (39)	1
Infection	12 (40)	332 (48)	0.46
Oncological	2 (7)	47 (7)	1
ICU mortality, <i>n</i> (%)	5 (17)	61 (8.8)	0.18
Ventilator-free days in 28 d	4.9 [0–17]	22 [16–24]	< 0.0001
ICU-free days in 28 d	0.5 [0–18]	19 [11–22]	< 0.0001

VAT = ventilator-associated tracheobronchitis.

Data are median [IQR] unless otherwise specified. *p* values less than 0.05 are marked in bold.