Humidification during mechanical ventilation to prevent endotracheal tube occlusion in critically ill patients: A case control study

Hasan M. Al Dorzi[1,2,3]**, Alaaeldien G. Ghanem**[1]**, Mohamed Moneer Hegazy**[1]**,
Amal AlMatrood**[4]**, John Alchin**[4]**, Mohammed Mutairi**[5]**, Ahmad Aqeil**[5]**, Yaseen M. Arabi**[1,2,3]

[1]*Intensive Care Department, King Abdulaziz Medical City, Ministry of National Guard-Health Affairs, Riyadh, Saudi Arabia,* [2]*King Abdullah International Medical Research Center, Riyadh, Saudi Arabia,* [3]*College of Medicine, King Saud bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia,* [4]*Nursing Services/ Critical Care, King Abdulaziz Medical City, Ministry of National Guard-Health Affairs,Riyadh, Saudi Arabia,*

[5]*Respiratory Care Services, King Abdulaziz Medical City, Ministry of National Guard-Health Affairs, Riyadh, Saudi Arabia*

Address for correspondence:
Prof. Yaseen M. Arabi, ICU2, Mail Code 1425, PO Box 22490, King Abdulaziz Medical City, Riyadh, 11426, Kingdom of Saudi Arabia.
E-mail: yaseenarabi@yahoo.com

Access this article online

Quick Response Code:

Website:
www.thoracicmedicine.org

DOI:
10.4103/atm.atm_135_21

Abstract:

BACKGROUND: Endotracheal tube (ETT) occlusion is a potentially life-threatening event. This study describes a quality improvement project to prevent ETT occlusion in critically ill patients.

METHODS: After a cluster of clinically significant ETT occlusion incidents at a tertiary-care intensive care unit (ICU), the root cause analysis suggested that the universal use of heat moisture exchangers (HMEs) was a major cause. Then, we prospectively audited new ETT occlusion incidents after changing our practices to evidence-based active and passive humidification during mechanical ventilation (MV). We also compared the outcomes of affected patients with matched controls.

RESULTS: During 100 weeks, 18 incidents of clinically significant ETT occlusion occurred on a median of 7 days after intubation (interquartile range, 4.8–9.5): 8 in the 10 weeks before and 10 in the 90 weeks after changing humidification practices (8.1 vs. 1.0 incidents per 1000 ventilator days, respectively). The incidents were not suspected in 94.4%, the peak airway pressure was >30 cm H_2O in only 25%, and 55.6% were being treated for pneumonia when ETT occlusion occurred. Compared with 51 matched controls, ETT occlusion cases had significantly longer MV duration (median of 13.5 vs. 4.0 days; $P = 0.002$) and ICU stay (median of 26.5 vs. 11.0 days; $P = 0.006$) and more tracheostomy (55.6% vs. 9.8%; $P < 0.001$). The hospital mortality was similar in cases and controls.

CONCLUSIONS: The rate of ETT occlusion decreased after changing humidification practices from universal HME use to evidence-based active and passive humidification. ETT occlusion was associated with more tracheostomy and a longer duration of MV and ICU stay.

Keywords:

Complications, cost, heat moisture exchanger, intensive care, intratracheal intubation, mechanical ventilation

Occlusion of the endotracheal tube (ETT) by debris and organized secretions may occur while providing mechanical ventilation (MV) for critically ill patients. Narrowing of ETT is probably a common occurrence.[1,2] Studies that evaluated ETTs using acoustic reflectometry showed that their intraluminal volume got smaller after intubation.[3,4] The ETTs from 101 patients who required MV for >24 h were evaluated after extubation.[3] They had smaller volumes than unused ETTs (average difference in ETT segment volumes was 9.8%; range, 0%–45.5%).[3] Another similar study found a volume reduction above 10% in 60.8% of ETTs with the mean difference in ETT segment volumes of 15.2% (range, 0%–66%).[4] Clinically significant ETT occlusion is probably less common.[1,2]

The risk factors for ETT occlusion include thick or bloody respiratory secretions, mucosal sluffing,[5] bacterial colonization of the ETT with biofilm formation,[6] and possibly the duration of intubation.[3,4,7] ETT occlusion has been associated with the humidification of inhaled gases during MV, but this association has not been consistent. In several observational studies, the use of heat moisture exchanger (HME) has been found to be associated with higher rates of ETT occlusion compared with active humidification.[2,8] However, other studies found no association between inhaled gas humidification method and ETT occlusion.[7] A systematic review of 18 randomized controlled trials (2442 adult intensive care unit [ICU] patients) found that the incidence of artificial airway occlusion was not different in patients treated with HMEs versus heated humidifiers (HHs) (relative risk, 1.85; 95% confidence interval [CI], 0.79–4.34).[9]

ETT occlusion in the ICU setting can be life-threatening and can result in increased morbidity, including pneumonia and pulmonary edema.[10] Its early recognition and prevention are important goals. As the literature on ETT occlusion in the ICU setting is scarce, we described the results of a quality improvement project that aimed at preventing ETT occlusion in critically ill patients and evaluated the impact of ETT occlusion on the outcomes of patients.

Methods

Setting
This case-control study was a part of a quality improvement project that started after a cluster of ETT occlusion incidents. It was conducted between October 2016 and September 2018 at the six adult (≥14-year-old) noncardiac ICUs of King Abdulaziz Medical City, a 1200-bed tertiary-care center in Riyadh, Saudi Arabia. The units were the general ICU (21 beds), Trauma ICU (TICU, 8 beds), Neurosciences Critical Care Unit (NCCU, 8 beds), Surgical ICU (SICU, 9 beds), the Oncology/Transplant ICU (12 beds), and the Intermediate Care Unit (IMCU, 14 beds). These units admitted various categories of critically ill patients and were covered by board-certified intensivists with onsite coverage 24 h per day, 7 days per week.[11] The Institutional Review Board of the Ministry of National Guard Health Affairs approved this study.

The routine respiratory care
Respiratory therapists provided specialized care to patients in these ICUs with a respiratory therapist-to-patient ratio of approximately 1:5. During this study period, ETTs that had subglottic secretion drainage were used for intubation. The routine care for mechanically ventilated patients included endotracheal suctioning of respiratory secretions four hourly and as needed using a closed suctioning system, which was changed every 72 h or as clinically indicated. Saline instillation during suctioning was not routinely performed but was used in case of thick secretions on as needed basis. Open suctioning was performed if closed suctioning was not effective. Ventilator circuits were changed in between patients or if they became soiled or damaged. For years before the improvement project, humidification of inhaled gases was routinely done using HMEs (Pall Ultipor® 25 filter) which were changed daily or when visibly soiled. HHs were available but there were no clear guidelines on the indications of their use in the departmental policy. In our ICUs, the adequacy of gas humidification, by directly measuring humidity or by evaluating its surrogate markers (i.e., secretion characteristics and visual observation of condensate in the tubings),[2] was not monitored during the routine bedside care.

The quality improvement project
After a cluster of ETT occlusion incidents that were clinically significant, defined as the requirement to change the ETT and intubation using a new one, a multidisciplinary taskforce analyzed 8 incidents that occurred between October 25, 2016, and January 3, 2017, examined respiratory care practices, such as ETT suctioning and gas humidification, and investigated the potential causes. The root cause was determined to be the overuse of passive humidification of inhaled gases using HME. Then, the humidification policy for patients on MV was updated according to the 2012 clinical practice guideline of the American Association for Respiratory Care.[12] The guideline recommended that all patients with an artificial airway requiring MV should receive continuous humidification of inspired gases and suggested that during invasive MV active humidification should provide a humidity level between 33 and 44 mg H_2O/L and gas temperature between 34°C and 41°C at the circuit Y-piece with a relative humidity of 100% and that HMEs should provide a minimum of 30 mg H_2O/L. Table 1 describes the humidification guidelines that we implemented in our ICUs. The results of the root cause analysis and the policy changes were presented to the ICU staff. Moreover, the number of HHs (Fisher and Paykel Healthcare humidifiers) was increased after securing a budget from the hospital administration. Using a standardized form, we then audited all ETT occlusion cases that required changing the ETT and that occurred after the initial cluster till September 30, 2018. Auditing of humidification practices and active feedback were periodically performed afterwards.

Data collection
In this case-control study, cases were the incidents of ETT occlusion from October 25, 2016, to September 30, 2018. We excluded patients who had occlusion of

the tracheostomy tube. Controls were ICU patients admitted to the adult noncardiac ICUs within the study period, received MV and did not have ETT occlusion. Depending on availability, 1–3 controls were randomly selected for each ETT occlusion case and were matched for clinical variables that usually affected the outcome of critical illness. These variables were age ±2 years, Acute Physiology and Chronic Health Evaluation (APACHE) II score ±2 points, and admission category (Medical, Surgical, trauma).

The collected data for cases and controls included demographics, type of admission (medical, surgical trauma), admission APACHE II score, admission Glasgow Coma Scale, use of vasopressors, pertinent laboratory tests on ICU admission, and urine output in the first ICU day. For cases, we noted the location of intubation, ETT size, time of changing the ETT (day shift 0800–1600, night shift: 1600–0800), days from intubation to ETT occlusion, humidification type, characteristics of endotracheal secretions before ETT change, peak airway pressures before and after ETT change, presence of pneumonia before ETT occlusion, and cultures of deep tracheal aspirates within 7 days of the ETT occlusion incident. We also evaluated the outcomes (mortality, duration of MV, length of stay in the ICU, and hospital) of cases and controls.

We also analyzed the raw costs of the consumables of passive versus active humidification systems for a theoretical patient intubated for 7 days. The needed consumables for such a patient were estimated by senior respiratory therapists working in our ICUs. We also obtained the costs of the reusable components of the active humidification systems. All costs were derived from the hospital administrative data and were calculated in 2018 values.

Table 1: Guidelines for humidification of inhaled gases for patients with invasive mechanical ventilation

Guidelines for active humidification
Expected duration of mechanical ventilation >96 h
Duration of mechanical ventilation of 72 h with no plan for extubation on the next day
ARDS patients who are managed by lung protective low tidal volume strategy (a contraindication for HME due to increased dead space)
Patients who have with large, thick secretion from the ETT (a contraindication for HME)
Patient with bloody secretion from the ETT (a contraindication for HME)
Patient with minute ventilation >10 L/min
Hypothermic patient with temperature <32°C
Patient with bronchopulmonary fistula (exhaled tidal volume <70% of inhaled tidal volume)
Guidelines on the use of HMEs
Expected intubation duration for <96 h
Absence of any contraindication

ARDS=Acute respiratory distress syndrome, HME=Heat moisture exchangers, ETT=Endotracheal tube

Statistical analysis

The rate of ETT occlusion was calculated as a percentage of intubated patients for ≥24 h and as the number of events per 1000 ventilator days. Quantitative variables were presented as median with the first and third quartiles (Q1, Q3). Qualitative variables were presented as frequency and percentages. Cases and controls were compared using the Fisher's exact test or Mann–Whitney U test, as appropriate. The Wilcoxon Signed-Ranks Test was used to assess the difference in peak airway pressure before and after the incident and changing the ETT. A $P < 0.05$ was considered significant. The analysis was performed using Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) version 15.

Results

In this study, 18 incidents of ETT occlusion were reported in 18 different patients in the 6 ICUs during the 100-week study period. Figure 1 demonstrates examples of three incidents of ETT occlusion that were observed in our units. Eight incidents of ETT occlusion occurred before the quality improvement project (October 5, 2016, to January 3, 2017; 10-week period) and 10 incidents after (January 4, 2017, to September 30, 2018; 90-week period). In the before-period, ETT occlusion occurred in 8.2% of patients requiring MV for ≥24 h (95% CI, 3.6%–15.6%) at 8.1 incidents per 1000 ventilator days (95% CI, 3.5%–15.9). In the after-period (January 4, 2017 to December 31, 2017), ETT occlusion occurred in 0.9% (95% CI, 0.4%–1.8%) of patients requiring MV for ≥24 h at 1.0 incidents per 1000 ventilator days (95% CI, 0.4–2.0). Figure 2 is a run chart of the number of ETT occlusion incidents during 10-week periods and suggests that the ETT occlusion incidents decreased significantly after the implementation of changes in inhaled gas humidification.

The characteristics of the patients who had ETT occlusion are described in Table 2. The patients had a median age of 64 years, were predominantly males, were mostly admitted for medical reasons rather than postoperatively and after trauma and had a median APACHE II score of 17.

The ETT occlusion incidents are described in Table 3. They occurred in the different ICUs on a median of 7 days after intubation (Q1, Q3: 4.8, 9.5). The vast majority (94.4%) were not suspected in the preceding 24 h. Most (61.1%) incidents were detected during the day shift (0700–1600). Respiratory secretions on ETT suctioning were thick and moderate in the amount in most ETT incidents (ETT) [Table 3]. Secretions were bloody in 10/18 (55.6%) patients. HME was used for humidification in all incidents except one incident which occurred while the patient on HH. Peak airway pressure >30 cm H_2O occurred in only 25% of incidents.

Table 2: Characteristics of patients who had endotracheal tube occlusion (cases) and controls

	Patients with ETT occlusion (*n*=18), *n* (%)	Controls* (*n*=51), *n* (%)	P
Age (years), median (Q1–Q3)	64.0 (40.0-71.3)	64.0 (40.0-72.0)	1.0
Male gender	13 (72.2)	27 (52.9)	0.15
Body mass index (kg/m²), median (Q1–Q3)	25.1 (20.2-29.0)	26.0 (23.3-29.8)	0.50
Admission category			
Medical	11 (61.1)	34 (66.7)	0.91
Surgical	4 (22.2)	10 (19.6)	
Trauma	3 (16.7)	7 (13.7)	
APACHE II score, median (Q1–Q3)	17.0 (14.0-32.0)	17.0 (14.0-28.0)	0.97
Glasgow coma scale on ICU admission, median (Q1–Q3)	14 (6-15)	10 (7-15)	0.54
Shock requiring vasopressors	11 (61.1)	30 (58.8)	0.87
Chronic medical illness			
Congestive heart failure	3 (16.7)	7 (14.6)	1.0
Chronic respiratory disease	1 (5.6)	5 (10.4)	1.0
Chronic kidney disease	2 (11.1)	4 (7.8)	0.65
Laboratory findings on ICU admission, median (Q1–Q3)			
Creatinine (µmol/L)	107 (66-245)	76 (60-168)	0.21
Platelet count×10⁹/L	284 (132.5-334)	202 (140-255)	0.09
Bilirubin (µmol/L)	15 (9-24)	17 (8-31.5)	0.84
INR	1.1 (1.1-1.5)	1.3 (1.1-1.6)	0.91
Lactate (mmol/L)	1.8 (1.2-6.3)	1.6 (1.0-3.5)	0.64
Urine output on the first ICU day (ml), median (Q1–Q3)	2084 (407.5-3097.5)	940 (399-1760)	0.21

*The cases and controls were matched for age, APACHE II score and admission category. APACHE=Acute physiology and chronic health evaluation, ETT=Endotracheal tube, Q1=First quartile, Q3=Third quartile, ICU=Intensive care unit, INR=International normalized ratio
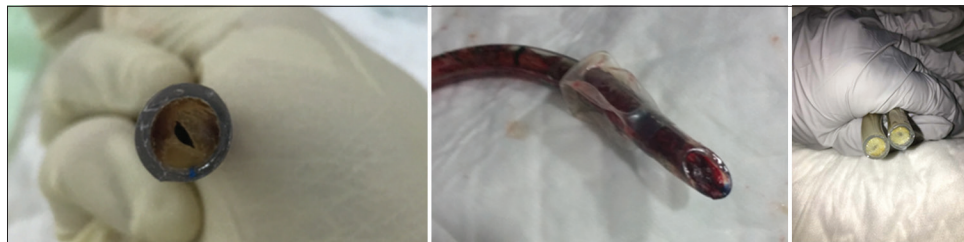

Figure 1: Pictures of three endotracheal tubes with significant occlusion
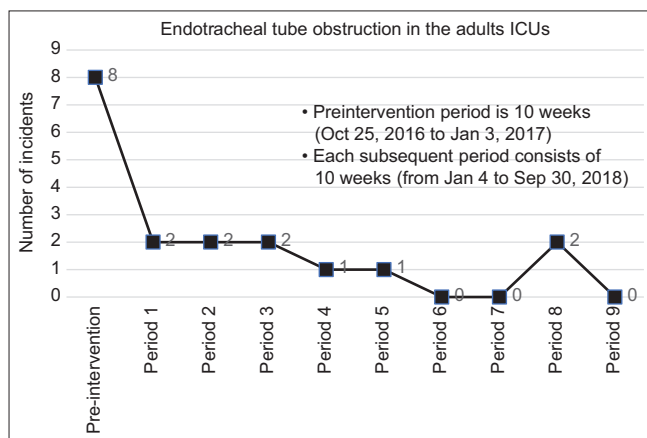

Figure 2: Run chart of the number of clinically significant endotracheal tube occlusion incidents before and after the quality improvement project

However, it went down significantly after changing the ETT (*P* = 0.01). Most patients (55.6%) were being treated for pneumonia when ETT occlusion occurred. Four patients had methicillin-sensitive *Staphylococcus aureus*.

Three patients had resistant organisms (*Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*).

Outcomes

Table 4 describes the outcomes of patients. None of the cases had pneumothorax. Even though ETT occlusion was associated with cardiac arrest in one patient and peri-cardiac arrest state in another, the mortality of cases and controls was similar (hospital mortality 38.9% vs. 35.5%, respectively; *P* = 0.79). ETT occlusion cases had a significantly longer duration of MV (median of 13.5 vs. 4.0 days; *P* = 0.002), more need for tracheostomy (55.6% vs. 9.8%; *P* < 0.001) and longer stay in the ICU (median of 26.5 vs. 11.0 days; *P* = 0.006).

Cost analysis

For a patient intubated for 7 days, the raw cost of a passive humidification system (3 HME units every 2 days on average and one single-use non-heated circuit)

was estimated at 25 USD. For the same patient, the raw cost of an active humidification system (one heated circuit, one single-use humidifier chamber, and two water irrigation sets per day on average) was estimated at 61 USD. The cost of one reusable active humidification system (humidifier machine, temperature probe, and heater connector), already purchased with the ventilators used in our ICUs, was 2890 USD.

Discussion

In this study, our main findings were the following: Clinically significant ETT occlusion incidents were rare and were frequently not clinically suspected before they became clinically significant; there was a decrease in ETT incidents after changing the humidification of inhaled gases from passive for all intubated patients to guideline-based humidification; ETT incidents were associated with increased morbidity but not mortality.

Table 3: Description of endotracheal occlusion incidents in cases (*n*=18)

	n (%)
Intubation location	
Emergency department	5 (27.8)
Intensive care unit	6 (33.3)
Operating room	2 (11.1)
Ward	3 (16.7)
Another hospital	2 (11.1)
Number of days of intubation before the incident (days), median (Q1–Q3)	7.0 (4.8-9.5)
ETT size, median (Q1–Q3)	7.5 (7.5-8.0)
Gas humidification	
Heat moisture exchanger	17 (94.4)
Heated circuit	1 (5.6)
Peak airway pressure (cm H_2O), median (Q1–Q3)	
Before	26.0 (24.0-30.5)
After	20.0 (16.0-23.0)
Description of respiratory secretions before the incident	
Thin; thick	3(16.7);15(83.3)
Small; moderate; large	5 (27.8); 10(55.6);3(16.7)
Bloody; nonbloody	8(44.4);10(55.6)
Pneumonia diagnosis at the time of the incident	10 (55.6)
Multidrug resistant organisms	3 (16.7)

ETT=Endotracheal tube, Q1=First quartile, Q3=Third quartile

The epidemiology of clinically significant ETT occlusion in the ICU setting is not well known. The ETT lumen gets smaller with time after intubation.[3,4] What is important is the clinical significance of such occurrence. Older studies suggested that clinically significant ETT occlusion occurs in up to 8.8%.[1,13] A recent study in 110 adult patients with COVID-19 patients, 28 (25.5%) patients required an urgent change of their ETT due to occlusion.[5] In our study, the occurrence of ETT occlusion was uncommon occurring in <2% of patients on MV for ≥1 day. This could be due to the changes in MV practices and improvement in humidification including the manufacturing of HMEs. Nevertheless, ETT occlusion may have been under-recognized or was not noted.

ETT occlusion typically results from the adherence of debris, blood, and secretions on its inner surface. A pathologic examination of a specimen from the material occluding an ETT of a patient with COVID-19 demonstrated sloughed tracheobronchial tissue and inflammatory cells in a background of dense mucin.[5] Biofilm-forming bacteria may increase the risk of ETT obstruction. In this study, most patients had thick secretions and four patients who developed ETT occlusion had *Staphylococcus aureus* cultured from the respiratory secretions. *Staphylococcus aureus* is well known to form biofilms.[14]

ETT occlusion may lead to hypoxia, hypercapnia, respiratory distress, increased work of breathing, failure of spontaneous breathing trials, and delayed extubation. In extreme cases, it may be a medical emergency and may lead to cardiac arrest. We observed that the ETT occlusion incidents were unsuspected and required urgent ETT change (38.9% of cases in the afterhours). The peak airway pressure was not always very high. In this study, the median peak pressure was 26 cm H_2O and went down by 6 cm H_2O after ETT change. In another study, improvement in peak airway pressure with ETT exchange occurred in 78.9% of patients with a median change of 12 cm H_2O (interquartile range 2–17.5).[5] The study also found improvement in arterial blood gases after ETT change.[5] The pattern of expiratory flow may indicate ETT occlusion early, whereas increased peak pressure is usually a late event.[15]

Table 4: Outcomes of patients who had endotracheal tube occlusion (cases) and controls

	Cases with ETT occlusion (*n*=18)	Controls* (*n*=51)	*P*
Hospital mortality, *n* (%)	7 (38.9)	18 (35.5)	0.79
ICU mortality, *n* (%)	5 (27.8)	11 (21.6)	0.75
Tracheostomy, *n* (%)	10 (55.6)	5 (9.8)	<0.001
Length of stay in hospital (days), median (Q1–Q3)	81.5 (26.0-120)	29.5 (17.0-94.3)	0.09
Length of stay in ICU (days), median (Q1–Q3)	26.5 (13.3-67.5)	11.0 (3.0-29.0)	0.006
Duration of mechanical ventilation (days), median (Q1–Q3)	13.5 (10.3-27)	4.0 (2.0-14.0)	0.002

*The cases and controls were matched for age, APACHE II score and admission category. The corresponding *P* values were 1.0, 0.97 and 0.91, respectively.
ETT=Endotracheal tube, ICU=Intensive care unit, Q1=First quartile, Q3=Third quartile, APACHE=Acute physiology and chronic health evaluation

This study was triggered by a cluster of clinically significant ETT occlusion incidents occurring within 10 weeks where all patients were on HME for inhaled gas humidification. Our root cause analysis suggested that HME may be responsible for these incidents. Knowing that different brands provide different levels of moisture, HMEs may not provide adequate humidification. This may be exacerbated by longer HME use and higher tidal volumes. Hence, a cascade of events occurs that include thickening of mucus, damage of mucosa, and desquamation of epithelial cells.[16] This material may adhere to the inside of ETT and gradually occludes the tube. The literature on the association between inhaled gas humidification and ETT shows mixed findings, and it is limited by the study sample sizes and the differences in methods. In 170 ICU patients on HME, ETT occlusion, defined as an inability to ventilate the patient, which resolved after emergency ETT change, occurred in 15 (8.8%) patients over 8 months.[1] When cascade humidification was used instead of HME for 81 patients, only one (1.2%) ETT occlusion occurred over 4 months ($P < 0.01$).[1] A prospective observational study of patients who required intubation found that the incidence of ETT occlusion was 5.7% in the HME group and 0% in the HH group.[13] Another study also found that ETT resistance increased significantly more with HME than with HH in patients who required MV for >48 h.[8] However, such findings were not seen in other studies. A prospective cohort study in an ICU that had 22 patients on HH and 22 on HME found that the ETT resistance increased by an average of 53% from intubation to extubation with no significant difference between the HH and HME groups.[7] In a randomized controlled trial that compared HME (163 patients) with HH (147 patients), none of the patients had ETT occlusion.[17] A systematic review of 18 randomized controlled trials found that the incidence of artificial airway occlusion was not different in patients treated with HMEs versus HHs (relative risk, 1.853; 95% CI, 0.792–4.338).[9] In the subgroup analyses, the incidence of airway occlusion was higher in HMEs compared with HHs with nonheated wire (relative risk, 3.776; 95% CI, 1.560–9.143).[9] The meta-regression found that studies with a high prevalence of pneumonia favored HMEs.[9] In a more recent study, ETT occlusion occurred in 25.5% of a cohort of patients with COVID-19, all were on HH.[5] We have observed a significant reduction in ETT occlusion cases after changing gas humidification practices. However, compliance with our humidification guideline was not 100% (90% of the ETT occlusion incidents occurred while the patients on HME in the after-period), which likely led to sporadic ETT occlusion incidents. This suggests the need for procedures that facilitate project sustainability, such as increasing staff involvement and buy-in and performing periodic audits to monitor progress with active feedback.[18]

Improvement in ETT manufacturing may prevent ETT occlusion. Micropatterned ETTs significantly reduced intraluminal biofilm formation by 71% ($P = 0.02$) compared to standard care ETTs.[19] In a vitro model, the micropatterned ETTs had significantly less lumen occlusion compared with standard care ETTs.[19] Devices that clear mucus and debris from an ETT and restore luminal patency have been produced and seem to be effective.[20] In one study, 74 patients were randomized to either the use of a novel device for ETT cleaning every 8 h or standard of care (blind tracheal suction) only.[21] The device led to reduced mucus accumulation ($P = 0.004$) and reduced occlusion (6.3 ± 1.7 vs. $8.9 \pm 7.6\%$; $P = 0.04$).[21] In addition, there was a trend in the device group toward reduced ETT-based biomass of bacteria known to cause ventilator-associated pneumonia.[21]

The clinical consequences of ETT occlusion are not well studied. In our matched case-control analysis, we found that ETT occlusion was associated with a longer duration of MV, a longer stay in the ICU, and more need for tracheostomy. ETT occlusion may have led to the failure of spontaneous breathing and weaning trials, which would prolong MV. However, ETT occlusion was not associated with increased mortality. The raw costs of consumables needed for active humidification, which may reduce ETT occlusion incidents and the associated morbidity, was higher than those of HME-based humidification by approximately 36 USD for every 7 days of MV. This increase cost is relatively modest and might be justifiable.

The findings of this study should be interpreted with caution. It is limited by the retrospective collection for some data and by being performed at one tertiary-care hospital. Some incidents of ETT occlusion may have been missed, but we focused on clinically significant incidents, minimizing this possibility. We did not have the number of ventilator days for patients admitted to the ICU from January 1 to December 31, 2018. Advantages include the outcome data analysis, which has not been performed in previous studies.

Conclusions

Clinically significant ETT occlusion was rare in critically ill patients but was probably underrecognized. After a quality improvement project implementing an evidence-based guideline for humidification of inhaled gas during MV, there was a decrease in ETT occlusion incidents. ETT occlusion was associated with increased morbidity in the form of a longer duration of MV, longer stay in the ICU, and more need for tracheostomy.

References

1. Cohen IL, Weinberg PF, Fein IA, Rowinski GS. Endotracheal tube occlusion associated with the use of heat and moisture exchangers in the Intensive Care Unit. Crit Care Med 1988;16:277-9.

2. Al Ashry HS, Modrykamien AM. Humidification during mechanical ventilation in the adult patient. Biomed Res Int 2014;2014:715434.

3. Shah C, Kollef MH. Endotracheal tube intraluminal volume loss among mechanically ventilated patients. Crit Care Med 2004;32:120-5.

4. Boqué MC, Gualis B, Sandiumenge A, Rello J. Endotracheal tube intraluminal diameter narrowing after mechanical ventilation: Use of acoustic reflectometry. Intensive Care Med 2004;30:2204-9.

5. Rubano JA, Jasinski PT, Rutigliano DN, Tassiopoulos AK, Davis JE, Beg T, *et al.* Tracheobronchial slough, a potential pathology in endotracheal tube obstruction in patients with coronavirus disease 2019 (COVID-19) in the intensive care setting. Ann Surg 2020;272:e63-5.

6. Coppadoro A, Bittner E, Berra L. Novel preventive strategies for ventilator-associated pneumonia. Critical Care. 2012;16(2):210.

7. Morán I, Cabello B, Manero E, Mancebo J. Comparison of the effects of two humidifier systems on endotracheal tube resistance. Intensive Care Med 2011;37:1773-9.

8. Jaber S, Pigeot J, Fodil R, Maggiore S, Harf A, Isabey D, *et al.* Long-term effects of different humidification systems on endotracheal tube patency: Evaluation by the acoustic reflection method. Anesthesiology 2004;100:782-8.

9. Vargas M, Chiumello D, Sutherasan Y, Ball L, Esquinas AM, Pelosi P, *et al.* Heat and moisture exchangers (HMEs) and heated humidifiers (HHs) in adult critically ill patients: A systematic review, meta-analysis and meta-regression of randomized controlled trials. Crit Care 2017;21:123.

10. Udeshi A, Cantie SM, Pierre E. Postobstructive pulmonary edema. J Crit Care 2010;25:508.e1-5.

11. Arabi Y, Alshimemeri A, Taher S. Weekend and weeknight admissions have the same outcome of weekday admissions to an intensive care unit with onsite intensivist coverage. Crit Care Med 2006;34:605-11.

12. American Association for Respiratory Care, Restrepo RD, Walsh BK. Humidification during invasive and noninvasive mechanical ventilation: 2012. Respir Care 2012;57:782-8.

13. Doyle A, Joshi M, Frank P, Craven T, Moondi P, Young P. A change in humidification system can eliminate endotracheal tube occlusion. J Crit Care 2011;26:637.e1-4.

14. Periasamy S, Joo HS, Duong AC, Bach TH, Tan VY, Chatterjee SS, *et al.* How *Staphylococcus aureus* biofilms develop their characteristic structure. Proc Natl Acad Sci U S A 2012;109:1281-6.

15. Kawati R, Lattuada M, Sjöstrand U, Guttmann J, Hedenstierna G, Helmer A, *et al.* Peak airway pressure increase is a late warning sign of partial endotracheal tube obstruction whereas change in expiratory flow is an early warning sign. Anesth Analg 2005;100:889-93.

16. Lucero PF, Park DW, Regn DD. Humidification in intensive care medicine: General approach to selected humidification devices and complications of mechanical ventilation. Humidification in the Intensive Care Unit. Springer, Berlin, Heidelberg; 2012. p. 117-21.

17. Kollef MH, Shapiro SD, Boyd V, Silver P, Von Harz B, Trovillion E, *et al.* A randomized clinical trial comparing an extended-use hygroscopic condenser humidifier with heated-water humidification in mechanically ventilated patients. Chest 1998;113:759-67.

18. Doyle C, Howe C, Woodcock T, Myron R, Phekoo K, McNicholas C, *et al.* Making change last: Applying the NHS institute for innovation and improvement sustainability model to healthcare improvement. Implement Sci 2013;8:127.

19. Mann EE, Magin CM, Mettetal MR, May RM, Henry MM, DeLoid H, *et al.* Micropatterned endotracheal tubes reduce secretion-related lumen occlusion. Ann Biomed Eng 2016;44:3645-54.

20. Mietto C, Foley K, Salerno L, Oleksak J, Pinciroli R, Goverman J, *et al.* Removal of endotracheal tube obstruction with a secretion clearance device. Respir Care 2014;59:e122-6.

21. Pinciroli R, Mietto C, Piriyapatsom A, Chenelle CT, Thomas JG, Pirrone M, *et al.* Endotracheal tubes cleaned with a novel mechanism for secretion removal: A randomized controlled clinical study. Respir Care 2016;61:1431-9.