A Literature Review on Strategies Preventing Ventilator-Associated Pneumonia: Role of Endotracheal Cuff Pressure, Cuff Material, and Cuff Shape

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Objectives: *To provide an overview of existing literature regarding the effects of ETT cuff pressure, cuff material, and cuff shape on VAP prevention in adult ventilated patients.* ***Background:*** *Ventilated patients are at risk of ventilator-associated pneumonia (VAP), which can result in many adverse consequences, such as increased length of stay, mortality, and hospital cost. Endotracheal tube (ETT) insertion is a commonly used measure for mechanical ventilation. However, ETT cuff pressure, special cuff material, and special cuff shape may affect the occurrence of VAP in ventilated patients, but the evidence for their effects on VAP prevention has not been synthesized.* ***Methods:*** *A literature review was conducted.* ***Findings:*** *Twenty-two studies involving 8,809 patients were included in this literature review. The reviewed studies showed inconsistent findings of the effects of continuous ETT cuff pressure monitoring (compared with intermittent pressure monitoring), polyurethane ultrathin tracheal tube (compared with polyvinyl chloride tracheal tube), and taper-shaped cuff (compared with conical-shaped cuff) on the prevention of VAP. Two studies reported consistent findings that silver-coated ETT significantly reduced bacterial load and incidence of VAP compared with uncoated ETT, but the evidence level was relatively weak.* ***Conclusion:*** *This literature review provides an initial and brief overview of the effects of ETT cuff pressure, cuff material, and cuff shape on preventing VAP. However, the effectiveness of these interventions remains inconclusive due to the inadequate evidence and low quality of previous studies. The intervention effects should be synthesized using a quantitative method and laboratory studies with rigorous design are needed to provide more solid evidence.*

Keywords: ventilator-associated pneumonia, endotracheal tube, cuff pressure, cuff material, cuff shape

INTRODUCTION

Ventilator-associated pneumonia (VAP) is one of the most common nosocomial infections developed in the intensive care unit (ICU), accounting for approximately one-third of nosocomial pneumonia cases (Torres et al., 2017). VAP, as defined by the Infectious Disease Society of America (IDSA), refers to pneumonia that occurs more than 48 hours after endotracheal intubation (Erb et al., 2016). Many critically ill patients in the ICU require endotracheal intubation and a mechanical ventilator for respiratory function support. These mechanically ventilated patients are at risk of developing VAP due to the loss of airway defense mechanisms. According to international epidemiological studies, the incidence of

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VAP ranges from 2 to 16 cases per 1,000 ventilator days (Rosenthal et al., 2012, 2010). A local study estimated the VAP incidence was to be 47.81 episodes per 1,000 ventilator days in Hong Kong (Kwan, Chan, Lau, & Yan, 2012).

VAP can concurrently increase the lengths of ICU stay and hospitalization, adverse outcomes, and costs of care (Torres et al., 2017). VAP was reported to prolong the duration of ICU stay by 5–7 days and hospital stay by two- to three-fold (Kollef, 2005). VAP may also increase the likelihood of death in ICUs. In particular, as reported by a meta-analysis, the overall attributable mortality of VAP is 13%, with higher risks for surgical patients and patients with mid-range illness at admission (Melsen et al., 2013). Besides, VAP is associated with a significant economic burden by increasing a hospital cost of approximately USD 40,000 per VAP patient (Kollef, Hamilton, & Ernst, 2012).

The guidelines for the treatment of VAP released by the IDSA with the American Thoracic Society (ATS) and the European Respiratory Society (ERS) have highlighted the importance of appropriate initial empiric antibiotic treatment of VAP to optimum patient outcomes (Kalil et al., 2016; Torres et al., 2017). However, a major concern that has increased is the risk of indiscriminate antibiotic usage, which can cause various antibiotic-associated side effects, such as increased resistance rates and Clostridium difficile colitis (Metersky & Kalil, 2018). Given the considerable negative consequences that may result from VAP, the prevention of VAP is a high priority for infection control and optimize patient outcomes. Moreover, reduction in VAP incidence prevents length of ventilation and ICU stay, hospital costs, and resource utilization, as well as improves patient outcomes (Sundar, Nielsen, & Sperry, 2012).

Bacterial colonization and pulmonary aspiration are two critical factors in the pathogenesis of VAP (Lambert et al., 2011). Commonly used approaches for preventing colonization include the use of oral antiseptics (e.g., Chlorhexidine) (Zuckerman, 2016), tooth-brushing (de Lacerda Vidal et al., 2017), or silver-coated tracheal (Rouze, Jaillette, Poissy, Preau, & Nseir, 2017); preventing pulmonary aspiration strategies include head-of-bed elevation (Harbrecht, 2012), endotracheal tube (ETT) with subglottic secretion drainage (Mareiniss et al., 2016), continuous tracheal tube cuff pressure (Dat et al., 2018), polyurethane ultrathin (PU) tracheal tube cuffs (Miller et al., 2011), and taper-shaped tracheal tube cuffs (Bowton, Hite, Martin, & Sherertz, 2013). Previous systematic reviews have demonstrated evidence that implementing head-of-bed elevation and the use of oral hygiene care (including the use of oral antiseptics, tooth-brushing, and subglottic suctioning) can actively reduce the incidence of VAP (Guerra et al., 2016; Muscedere et al., 2011; Niel-Weise et al., 2011).

However, reviews on the effects of combined ETT related strategies on VAP prevention are lacking. Increasing evidence in the literature suggests possible benefits of lower VAP risk and the use of a combination of continuous cuff pressure monitoring device (Dat et al., 2018), special tracheal tube materials (e.g., PU cuff and silver-coated cuff) (Miller et al., 2011; Rouze et al., 2017), and selecting taper-shaped cuff (Bowton et al., 2013) in VAP prevention. Given that these ETT related interventions are basic and common procedures in daily clinical practice, a better understanding of their role is necessary to facilitate the implementation of these approaches in VAP prevention. Thus, this study aims to review available evidence to evaluate the effects of ETT cuff pressure, ETT cuff material, and ETT cuff shape on preventing VAP.

METHODS

Search Strategy

A literature search for the following electronic databases: Medline, Pubmed, Embase, PsycInfo, and CINAHL was undertaken with no restriction of the date of publication. Search terms were "mechanical ventilat*," "endotracheal tube," "cuff pressure," "continuous cuff pressure," "automatic cuff pressure," "cuff material," "polyurethane cuff," "silver-coated cuff," "cuff shape," "taper-shaped cuff," "conical cuff," "ventilator-associated pneumonia," "VAP," and "nosocomial infection."

Selection of Studies

Inclusion criteria included: (a) participants are adult (aged ≥18 years) ventilated patients with an ETT in any hospital setting for 48 hours or more; (b) observational or experimental studies; (c) studies that evaluated the effects of ETT cuff pressure, ETT cuff material, and ETT cuff shape on preventing VAP. Studies without full-text and protocols, reviews, conference abstracts, clinical guidelines, or editorials were excluded.

RESULTS

Overview of the Studies

A total of 22 studies involving 8,809 patients underwent mechanical ventilation were identified and reviewed. The reviewed studies were published between 2006 and 2018. Of the reviewed studies, five (22.7%) were conducted in the United States, four were conducted in Spain (18.2%), and the others were conducted in Iran, France, Tunisia, Slovenia, Belgium, Italy, and India. Sixteen studies employed a randomized control trial (RCT) design, including two with clustered randomization; four were quasi-experimental studies with controls; two were single-group pre-test post-test studies. The sample sizes of reviewed studies ranged from 29 (Bulpa et al., 2013) to 2,849 (Bowton et al., 2013), with 6 studies enrolling less than 100 participants.

Effects of Cuff Pressure on VAP

Maintaining a cuff pressure of 20–30 cm H_2O is recommended for adequate seal and to reduce complications (Carhart, Stuck, & Salzman, 2016). Underinflation (less than 20 cm H_2O) of the tracheal tube cuff may not guarantee the delivery of positive pressure ventilation, which may cause air leakage around the cuff. Over-inflation (exceed 30 cm H_2O), on the other hand, can result in injury to the tracheal mucosa by inhibiting capillary blood flow. ETT cuff pressure usually decreases over time. Conventionally, the ETT cuff is inflated manually or intermittently by a manual pressure cuff device, which does not ensure the maintenance of cuff pressure within the normal range (Sole et al., 2011). Then, the incidence of microaspiration may increase if the cuff pressure is not properly monitored.

Three of the reviewed studies examined the effects of monitoring on the maintenance of ETT cuff pressure and found significant effects of continuous cuff pressure monitoring on maintaining normal cuff pressure compared with intermittent monitoring of cuff pressure (Nseir et al., 2011; Sole et al., 2011; Valencia et al., 2007). These studies found that both low cuff pressure (<20 cm H_2O) and high cuff pressure (>30 cm H_2O) occur more frequently when using manual checking method than using an automatic cuff pressure monitoring device ($p < .001$). Moreover, Nseir et al. (2011) found that continuous cuff pressure monitoring was significantly associated with reduced incidents of microaspiration (manual checking vs. continuous monitoring: 46% vs. 18%, $p = .002$) and lower VAP rates (manual checking vs. continuous monitoring: 26.2% vs. 9.8%, $p = .032$). However, Valencia et al. (2007) reported no significant differences in rates of VAP, causative microorganisms, and mortality between intervention group and control group. This result might be contributed by the non-systematic cultures of bacterial of oropharyngeal and tracheobronchial secretions, which may have led to non-significant differences in VAP rates.

In addition to the aforementioned three studies, another three studies assessed the effects of continuous cuff pressure control using an automatic device and reported significantly lower incidence of VAP (De Pascale et al., 2017; Lorente, Lecuona, Jimenez, Cabrera, & Mora, 2014a, 2014b) and healthcare cost (Lorente et al., 2014a) with continuous control group than intermittent control group. In another study, no significant differences were noted in the occurrence of VAP, witnessed aspiration events, 30-day mortality, and hospital length of stay between frequent

ETT cuff pressure monitoring (immediately after intubation, every 8 hours, and when clinically indicated) and infrequent ETT cuff pressure monitoring (immediately after intubation and when clinically indicated for an observed air leak or due to tube migration) (Letvin et al., 2018). A possible explanation is that even the frequency of cuff pressure monitoring in the frequent group was not enough to reduce the incidence of VAP, which may have contributed to the lack of differences.

Effect of ETT Materials on VAP

Using different tracheal tube materials may reduce microaspiration or bacterial colonization. ETTs are conventionally constructed of polyvinyl chloride (PVC). One disadvantage of this material is its tendency to form longitudinal folds on the surface of the cuff easily, which may cause pulmonary microaspiration. Several studies have compared different types of ETT cuff materials (including latex, silicone, and PU) to reduce the incidence of longitudinal folds, and found that PU-ETTs are superior in preventing of microaspiration than other types of ETTs (Hamilton & Grap, 2012; Lorente, Lecuona, Jimenez, Mora, & Sierra, 2007; Miller et al., 2011). Silver-coated ETT is another approach for reducing colonization. Microbial colonization can occur when microorganisms adhere onto the surface of the ETT cuff and then migrate toward the trachea and lungs. Silver-coated ETTs can prevent bacterial colonization because it is difficult for microorganisms to adhere to the surface of silver-coated ETTs (Ouanes et al., 2011).

PU-ETT

Eight studies evaluated the use of PU-ETTs on leakages and incidence of VAP. An RCT of 40 subjects found that PU-ETT was more resistant to leakages than the usual PVC-ETT (Lucangelo et al., 2008). Whereas, another RCT of 29 subjects demonstrated no significant difference in the occurrence of leakages between PU-ETT and PVC-ETT (Bulpa et al., 2013). The effects of PU-ETTs on the incidence of VAP were reported in the remaining six studies. Three studies found that the use of PU-ETT resulted in reducing the incidence of VAP compared with PVC-ETT (Lorente et al., 2007; Mahmoodpoor et al., 2013; Miller et al., 2011). PU material can minimize the formation of longitudinal folds on the ETT cuff surface and reduce microaspiration. Poelaert et al. (2008) also found that early post-operative pneumonia occurred less in cardiac surgical patients using PU-ETT than those using PVC-ETT (PU vs. PVC groups: 23% vs. 42%, $p < .03$). Conversely, the other two studies showed that PU-ETT was not superior to PVC-ETT in preventing VAP (Philippart et al., 2015; Suhas, Kundra, & Cherian, 2016). Despite, Suhas et al. (2016) reported that the use of PU-ETT significantly reduced the length of ICU stay.

Silver-Coated ETT

As microorganisms do not easily adhere to the surface of silver-coated ETTs, colonization is rare and the incidence of VAP decreases (Ouanes et al., 2011). Two RCTs assessed the effects of silver-coated ETT and demonstrated a significant reduction in the occurrence of VAP and bacterial load (Kollef et al., 2008; Rello et al., 2006). Rello et al. (2006) found that silver-coated ETT significantly delayed colonization, reduced colonization rate, and decreased bacterial load. Patients developed clinical signs with a bacterial load of ≥ 105 CFU (colony-forming unit)/mL for endotracheal aspirate or a bacterial load of ≥104 CFU/mL for BAL (Rello et al., 2006). Kollef et al. (2008) reported that patients receiving silver-coated ETT presented statistically significant reductions in VAP incidence (silver-coated vs. uncoated groups: 4.8% vs. 7.5%, $p = .03$), with a reduction in VAP incidence of 35.9%.

Effect of ETT Cuff Shape on VAP

Conventional ETTs usually use a cylindrical cuff. However, as the diameter of the trachea differs throughout its length, using a conventional ETT with a cylindrical-shaped cuff may not be able to occlude or seal the trachea effectively. Therefore, there is still a possibility for the occurrence of microaspiration. A taper-shaped (conical-shaped) ETT that could more effectively accommodate to natural variations in the size/diameter of the trachea was recently developed. The taper-shaped cuff can seal the trachea at one point, prevents fluid leak, thereby preventing pulmonary microaspiration (Dave, Frotzler, Spielmann, Madjdpour, & Weiss, 2010).

Seven reviewed studies evaluated the effects of taper-shaped cuff on VAP prevention. Two studies revealed that the use of taper-shaped cuff resulted in significantly less incidence of VAP compared to conventional cuff (Mahmoodpoor et al., 2017, 2013). On the contrary, the remaining five studies failed to demonstrate the significant effect of taper-shaped cuff on reducing incidence of VAP (Bowton et al., 2013; Jaillette et al., 2017; Millot et al., 2018; Monsel et al., 2016; Philippart et al., 2015). Moreover, no significant differences between taper-shaped cuff and conventional cuff were found for other outcomes, including microaspiration (Jaillette et al., 2017; Millot et al., 2018; Monsel et al., 2016), airway colonization (Millot et al., 2018; Philippart et al., 2015), and ICU length of stay and mortality (Jaillette et al., 2017; Mahmoodpoor et al., 2017; Millot et al., 2018).

DISCUSSION

This literature review provides an initial and brief overview of the effects of ETT cuff pressure, ETT cuff material, and ETT cuff shape on preventing VAP. Continuous monitoring and adjustment of the tracheal tube cuff pressure and the use of special ETT materials and cuff shapes are increasingly considered as important strategies for preventing VAP. However, the available evidence regarding the effectiveness of these interventions is far from conclusive.

The reviewed studies demonstrated inconsistent findings of the effects of continuous ETT cuff pressure monitoring, PU-ETT, and taper-shaped cuff on reducing VAP. Four out of five studies found continuous ETT cuff pressure monitoring significantly reduced VAP compared with intermittent monitoring (De Pascale et al., 2017; Lorente et al., 2014a2014b; Nseir et al., 2011). Whereas, this effect was not significant in the study by (Valencia et al., 2007). In terms of the effects of PU-ETT on the incidence of VAP compared with PVC-ETT, significant findings were showed by four out of six studies (Lorente et al., 2007; Mahmoodpoor et al., 2013; Miller et al., 2011; Poelaert et al., 2008), and the other two studies found no evidence about this effect (Philippart et al., 2015; Suhas et al., 2016). Similarly, two out of seven studies found that taper-shaped cuff significantly reduced VAP compared to conventional cuff (Mahmoodpoor et al., 2017, 2013); whereas, the remaining five studies reported the effect was not significant (Bowton et al., 2013; Jaillette et al., 2017; Millot et al., 2018; Monsel et al., 2016; Philippart et al., 2015). Notably, there were significant variations in study design, study populations, and other parameters that may influence outcomes across each reviewed study, which may have also contributed to the inconsistent findings.

Two of the reviewed studies reported consistent findings that silver-coated ETT significantly reduced bacterial load and incidence of VAP in comparison with uncoated ETT (Kollef et al., 2008; Rello et al., 2006). However, the evidence of this finding may be weakened by the methodological limitations of these two studies. For example, Kollef et al. (2008) did not control potential confounding factors, for example, the number of patients with chronic obstructive pulmonary disease, which may have contributed to the occurrence of VAP.

There were several limitations of the reviewed studies. Firstly, six studies did not employ a randomized design, that is, four studies used quasi-experimental design (Letvin et al., 2018; Lorente et al., 2014a, 2014b; Millot et al., 2018) and two studies utilized a single-group pre-test post-test design (Bowton et al., 2013; Miller et al., 2011). Secondly, the sample sizes of some studies were relatively small and not based on power analysis, which may result in an inaccurate estimation of intervention effects. Six studies recruited less than 100 patients (Bulpa et al., 2013; De Pascale et al., 2017; Lucangelo et al., 2008; Mahmoodpoor et al., 2013; Sole et al., 2011; Suhas et al., 2016). Thirdly, several studies did not control confounding factors that may influence intervention outcomes, such as control handwashing campaign (Miller et al., 2011), cultures of oropharyngeal and tracheobronchial secretions (Valencia et al., 2007), antibiotic consumption (Mahmoodpoor et al., 2017), and so on. Lastly, it was impossible to blind investigators and attending physicians and may not rule out the risk of bias. Therefore, the findings from this literature review should be cautiously interpreted.

In clinical practice, nurses are in-charge of monitoring the ETT cuff pressure and aid in the selection of appropriate tracheal tubes (material, shape). Nurses play an important role in implementing appropriate interventions to help prevent VAP. Despite some studies have explored the effect of tracheal cuff pressures, materials, and shapes on VAP incidence, the effectiveness of these approaches in reducing or preventing of VAP remains unclear due to the narrative synthesis method and methodological limitations of these studies. Therefore, a systematic review and meta-analysis of high-quality studies should be carried out to add evidence regarding the effectiveness of these interventions. Besides, more studies with rigorous design should be conducted to further examine the effectiveness of these interventions before implementing them in clinical practice. Given that the intervention parameters may be more beneficial in preventing VAP than the control parameters, which may induce ethical concerns, laboratory studies should be considered.

CONCLUSIONS

This literature review provides a brief and narrative summary of the effects of ETT cuff pressure, ETT cuff materials, and ETT cuff shape on the prevention of VAP. However, the existing knowledge is inadequate to draw clear conclusions about the effectiveness of these interventions on reducing VAP. A systematic review and meta-analysis of the intervention effects and rigorously-designed laboratory studies are required to provide more solid evidence.

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