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Effectiveness of subglottic suctioning in the prevention of ventilator associated pneumonia

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EFFECTIVENESS OF SUBGLOTTIC SUCTIONING IN THE PREVENTION
OF VENTILATOR ASSOCIATED PNEUMONIA

by

CODY WINSTON AMATO

A thesis submitted in partial fulfillment of the requirements
for the Honors in the Major Program in Nursing
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Thesis Chair: Dr. Mary Lou Sole

ABSTRACT

Ventilator-associated pneumonia (VAP) is the leading healthcare-acquired infection among ventilated patients in intensive care units (ICU). VAP is a serious patient complication that results in increased hospital length of stay, cost, morbidity, and mortality. The accumulation of subglottic secretions above the endotracheal tube (ETT) cuff increases the risk of VAP, as these secretions may leak around the cuff of the ETT resulting in aspiration and an increased risk for infection. An in depth literature review was done to determine the effectiveness of subglottic secretion aspiration (by means of specialized ETT tubes with intrinsic suction lumens) in decreasing the incidence rate of VAP. Evidenced-based data were gathered from the CINAHL Plus with Full Text, PubMed, and Cochrane Database of Systematic Reviews databases for this review. VAP guidelines recommend subglottic secretion aspiration as a means to prevent its occurrence. However, important variables such as suction pressure, frequency, secretion viscosity, and ETT cuff pressure and volume need to be considered. The interaction among these variables determines the effectiveness of subglottic secretion removal. The goal of this review was to highlight these interactions and provide evidenced-based information for critical care nurses to expand their understanding of the dynamics involved in subglottic secretion aspiration and how to efficiently use this practice to prevent VAP.

DEDICATION

I would like to thank all the instructors and mentors I have had throughout my academic career.

Your care, concern, and encouragement fueled my desire for excellence.

I would like to thank the few friends who have remained loyal to me over these years.

I appreciate your tolerance to my limitations and shortcomings.

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Introduction

Ventilator associated pneumonia (VAP) is a hospital acquired infection that develops 48 hours or more after a patient is intubated with an endotracheal or tracheostomy tube and is put on mechanical ventilation. VAP is the most common nosocomial infection in the intensive care unit (ICU) among mechanically ventilated patients (Davis, 2006). According to the 2009 National Healthcare Safety Network (NHSN) report, there were 8993 reported cases of VAP in critical care units. The highest rates were found in burn, neurologic, and trauma units (Edwards et al., 2009). These data are significant because relative to those without VAP, ventilated patients acquiring VAP have a nearly 45% increased mortality rate (Ibrahim, Tracy, Hill, Fraser, & Kollef, 2001). Mortality rates are highly variable due to individual circumstances such as comorbidities and the type of microorganism colonizing the lower airway. In addition to increased mortality rates, VAP is associated with increased hospital and ICU length of stay, duration of mechanical ventilation, and hospital charges exceeding \$40,000 (Muscedere et al., 2008).

The signs and symptoms of pneumonia are roughly the same for both ventilated and non-ventilated patients. The symptoms seen in critically ill ventilated patients include fever, increased respiratory or heart rate, increased purulent secretions, and possibly symptoms related to worsening hypoxemia (Bartlett, 2008). Several methods are used to diagnose VAP in this population. The differences between methods lie in their accuracy. The qualitative or clinical method uses the Clinical Pulmonary Infection Score (CPIS) scale to determine if a pulmonary infection is pneumonia based on certain signs and symptoms. Although this method of diagnosis is sensitive, it is not specific because the signs and symptoms can be caused by other ailments

(Chastre & Fagon, 2002). The quantitative method uses invasive techniques to match the signs and symptoms of pneumonia with a known causative organism. By culturing endotracheal aspirates, lower airway secretions, or bronchoalveolar lavage, an appropriate antibiotic can be selected, which decreases the risk of creating drug resistant organisms through the use of broad spectrum antibiotics (Davis, 2006). The most reliable method of identifying pneumonia and the causative organism is by culturing the pleural fluid (Bartlett, 2008), but this method is rarely used in the clinical setting.

VAP develops when the normally sterile lower airway becomes colonized by bacteria. Common bacterial organisms in ventilated patients include *Pseudomonas aeruginosa* and *Staphylococcus aureus*. The risk of acquiring either organism increases when the normal airway defenses are bypassed by mechanical interventions. The longer mechanical ventilation is used, the greater the risk of infection. *P. aeruginosa* and *S. aureus* both have drug resistant strains which increases the morbidity and mortality of VAP (Barlett, 2008). Bacteria are able to colonize and become infectious as a result of the lower airway losing its sterility when the defense mechanisms between the upper and lower airways are compromised due to the placement of an ETT (Pneumatikos, Dragoumanis, & Bouros, 2009). An ETT impairs mucociliary clearance and disrupts the cough reflex, which creates a direct pathway to the lower airway. Patient aspiration of these secretions is a significant factor in developing VAP. In addition to disrupting the normal host defense mechanisms, ETT placement injures the tracheal epithelium and allows for implantation of exogenous and endogenous bacteria in the tracheal mucosa (Pneumatikos I. A., Dragoumanis C. K., & Bouros D. E., 2009).

Problem

With an incidence rate between 8% and 68% (Labeau, Vandijck, Claes, van Aken, & Blot, 2007) and a mortality rate of 20% to 50% (Davis, 2006), preventing VAP in critically ill patients is a priority. One of the problems contributing to the development of VAP is the presence of the ETT tube itself. It impedes the respiratory systems normal defense mechanisms and creates a gateway for bacterial colonization in the lungs. The ETT balloon or cuff provides a platform where contaminated secretions can collect and pool. These pooled contaminants are known as subglottic secretions and can be aspirated by the patient (O'Keefe-McCarthy, 2006). The microaspiration of these secretions is a preventable etiological factor in the development of VAP (Safdar, Crnich, & Maki, 2005).

The importance of removing secretions from the subglottic space is recognized by the American Association of Critical-Care Nurses (AACN), American Thoracic Society (ATS), and the Centers for Disease Control and Prevention (CDC) as a VAP prevention measure and is incorporated into guidelines for preventing VAP (Seckel, 2007). However, in a study that analyzed the responses of twelve hundred critical care nurses only 36% reported performing regular subglottic suctioning (Cason, Tyner, Saunders, & Broome, 2007). The results of a multisite study conducted by Sole et al. (2003) states the policies on suctioning and airway management practices vary widely between hospitals and do not always reflect research-based practices (Sole et al., 2003).

Purpose

The purpose of this thesis is to provide the reader with an integrative review literature that analyzes the dynamics of subglottic secretions and their removal, how variations in

equipment affect removal, and how to best evacuate subglottic secretions. Additionally, the goal of this review is to educate nurses and positively influence their VAP prevention practices. This thesis will include how the critical care nurse should best intervene to prevent VAP given the research reviewed. These findings will hopefully reinforce the importance of aspirating subglottic secretions and provide further insight into where research can be done regarding this topic.

Method

For the purpose of this thesis, an integrative literature review was conducted related to endotracheal tubes with intrinsic suctioning capabilities, subglottic secretion removal, and the variables involved with efficient secretion removal. Literature reviews and recent evidenced based research findings were gathered from databases including CINAHL Plus with Full Text, PubMed, and Cochrane Database of Systematic Reviews. Inclusion criteria for this thesis included English written research articles and literature reviews that focused on removal of subglottic secretions to prevent VAP. In addition to this parameter, research articles were included only if written within the years 2000 and 2011 or were original research. Articles defining the pathophysiology of VAP were included to understand the nature of the problem. A detailed review of the articles selected and their relevance are described in Table 1. Articles not included were those that dealt solely with oral care, ETT suction, ventilator circuit management, or other VAP prevention strategies (Figure 2).

Background

The pathogenesis of VAP is a two step process that involves bacterial colonization of the respiratory tract followed by aspiration of contaminated secretions into the lungs. VAP can develop at any point in time; however it is often described as occurring during two distinct periods of time. The first period is defined as early onset VAP and develops within 48 to 96 hours after intubation. The second period is classified as late onset and occurs after 96 hours (Augustyn, 2007). An important note is pneumonia can only be diagnosed as ventilator associated if the patient has been mechanically ventilated for at least 48 hours. Early onset VAP is easier to treat because common organisms such as *Streptococcus pneumoniae* and *Staphylococcus aureus* are more susceptible to antibiotic therapy. However, late onset VAP is harder to treat with antibiotic therapy because antibiotic resistant bacteria such as *Pseudomonas aeruginosa* and Methicillin-resistant *Staphylococcus aureus* are usually colonizing the airway by this time (Augustyn, 2007).

The ETT bypasses the upper airway which interferes with mucociliary clearance, the cough reflex, and air filtration and humidification. These systems normally aid in filtering out contaminants before they reach the lower airway (Pneumatikos et al., 2009). The ETT moves past the epiglottis which normally separates the upper airway from the lower airway. The result is a direct connection between the two airways which drastically increases the risk of infection. Therefore, only the ETT cuff separates the contaminated upper airway from the sterile lower airway in the ventilated patient (Figure 1). Without appropriate intervention, the oropharyngeal region becomes populated by the previously mentioned virulent gram-negative organisms which can be aspirated by the patient.

Risk Factors

The presence of an ETT for greater than 48 hours places a patient at risk for VAP. However, there are modifiers that affect this basic principle which can increase the risk of acquisition. These modifiers are classified as host, device, or personnel related risk factors. An underlying medical condition such as chronic obstructive lung disease or a decreased level of consciousness is considered a host related risk factor. Device related risk factors include the presence of the ETT itself, the ventilator circuit, or additional invasive devices such as nasogastric tubes. These devices increase the risk of oral or gastric contamination and aspiration. Finally, failure to use proper technique or maintain hand hygiene increases the risk of cross contamination between the nurse and the patient and is considered personnel related risk factors (Augustyn, 2007)

Prevention Strategies

The goal is to interrupt the pathogenesis of VAP by preventing bacterial colonization of the oropharynx and gastrointestinal (GI) tract and protecting the lower airway from aspirants. This can be accomplished through early implementation of current clinical practice guidelines and appropriate use of preventive technologies.

Beginning with the ETT, intubation should only be considered if noninvasive ventilation is not indicated. If a patient requires invasive mechanical ventilation, the ETT should be placed via an oral route to avoid the increased risk of VAP associated with nasal intubation (Pierce & Sole, 2009, p.193). Intubation generally requires some degree of sedation to primarily prevent self-extubation, but also to allow the patient to take advantage of the ease of breathing. However, it is important to routinely decrease sedation for the purpose of weaning the patient

from the ventilator. Extubating as early as possible decreases the risk of VAP since the ETT is no longer present and normal upper airway defense mechanisms can resume (Efrati et al., 2010).

Two clinical practice guidelines aid in preventing the two critical occurrences that lead to VAP. The first is routine oral care and the second is head of bed elevation. Oral care or hygiene is the use of a sponge or toothbrush with an oral antiseptic to cleanse the inside of intubated patients' mouths. This care is provided to prevent bacterial colonization of the oral cavity. Failure to intervene in preventing colonization can lead to bacterial migration into the subglottic region above the cuff where contaminated secretions are subject to microaspiration (Efrati et al., 2010). The recommended elevation of the head of bed (HOB) is between 30°-45° (O'Keefe-McCarthy, Santiago, & Lau, 2008). The significance of elevating the HOB is to reduce the risk of aspirating oropharyngeal or GI secretions which can cause VAP. By implementing these strategies, key etiological components (colonization and aspiration) of VAPs pathology are reduced.

Appropriate use of intubation and ventilation equipment can also decrease the incidence of VAP. Although there are several preventive technologies to explore such as closed tracheal suction systems, frequency of ventilator circuit changes, and heat moisture exchangers, two of the most important device related interventions are the use of continuous aspiration of subglottic secretions (CASS) and maintenance of an effective ETT cuff pressure. ETT cuff pressure prevents leakage of subglottic secretions from around the cuff. The goal is to maintain an intracuff pressure of at least 20 cmH₂O to prevent this (Lorente, Lecuona, Jimenez, Mora, & Sierra, 2007). The use of CASS to prevent VAP is the focus of this paper. Factors that influence its role in VAP prevention will be covered in further detail.

Results

ETT with Continuous or Intermittent Suction

The accumulation of secretions in the subglottic region is of great concern when trying to prevent VAP. Patient aspiration of the pooled secretions must be avoided. The preferred method of removing these secretions is through a dedicated suction port located within the ETT. The suction port is just above the inflated cuff and is connected to continuous or intermittent suction to remove secretions that accumulate in the subglottic space (Depew & McCarthy, 2007). CASS-enabled ETTs come in a variety of brands; however, functionality of the different brands varies. Major differences exist in secretion evacuation time and probability of the lumen becoming occluded. In a study done by Mujica-Lopez, Pearce, Narron, and Rubin (2010), three ETTs were evaluated to determine their effectiveness in aspirating secretions pooled above the cuff. The Hi-Lo Evac (Mallinckrodt Medical; St. Louis, MO), Teleflex ISIS (Teleflex Medical; Research Triangle Park, NC), and Portex Blue Line SACETT (Smith Medical ASD Inc; Weston, MA) were chosen because they are capable of intrinsic suctioning and likely to be found in the critical care setting (Mujica-Lopez, Pearce, Narron, Perez, & Rubin, 2010). In a laboratory study using continuous and intermittent suctioning at varying pressures, each tube evacuated secretion simulants of varying viscosity and volume. The elapsed time to clear the secretions determined the efficiency of the intrinsic suctioning. It was shown that the Teleflex ISIS removed secretions more efficiently than the Hi-Lo Evac and the SACETT ($p < 0.0001$). Intermittent suctioning with high suction pressures (-100, -110, and -120 mmHg) applied 10 seconds on and 5 seconds off proved to be the most effective at clearing thin and thick secretions at 5 and 10 mL of volume pooled above the cuff. The ISIS tube also outperformed the others using continuous suction

pressures of -10, -15, and -20 mmHg for thin secretions and both volumes. It is important to note that when using continuous suctioning, none of the tubes evaluated could clear the thick secretions at either volume effectively utilizing -10 or -15 mmHg. The Hi-Lo Evac and SACETT tubes occluded at -20 mmHg while the ISIS tube did clear the secretions at -20 mmHg, but with a mean time of over 30 minutes (Mujica-Lopez et al., 2010).

The data from this study aids in identifying the best ETT for clearing subglottic secretions above the cuff and, therefore, reducing the risk of patient aspiration of pooled contents. It can be concluded that the Teleflex ISIS is the best choice in clearing secretions from the subglottic region when compared to the Hi-Lo Evac and Portex Blue Line SACETT. Although all three tubes provide the same results, the ISIS tube removed pooled secretions more efficiently. Upon review, it was found that the area of the ISIS tube's suction lumen is approximately 30% greater than then Hi-Lo Evac and SACETT (7.7mm^2 compared to 5.4mm^2 and 5.6mm^2 respectively). In addition, the area of the dorsal suction lumen (7.7mm^2) and suction tubing (8.5mm^2) of the ISIS is approximately 40% greater than the Hi-Lo Evac and SACETT ($2.8/5.6\text{mm}^2$ and $2.9/5.4\text{mm}^2$ respectively). The design of the ISIS allows for greater flow through the suction tubing reducing the likelihood of secretions occluding the lumen. Although the intrinsic suctioning of the ISIS is less prone to occlusion by secretions, it is more likely to occlude as a result of tissue obstructing the lumen. When compared to the Hi-Lo Evac tube at -120 mmHg of intermittent suction, the ISIS became occluded by tracheal tissue while the Hi-Lo Evac experienced minimal tissue occlusion (Mujica-Lopez et al., 2010).

Despite the ISIS tube being superior in removing secretions from the perspective of suction, the information presented raises concern of subglottic tissue trauma when using this

tube. Trauma to this region can cause inflammation and lead to infection. However, this is a problem that plagues all ETTs utilizing intrinsic suctioning to some degree (Depew & McCarthy, 2007). Additional research related to long-term effects of inflammation and erosion is needed.

ETT Cuff Pressure

The cuff surrounding an endotracheal tube aids in preventing aspiration of subglottic secretions. However, this can only be accomplished if a tight seal is formed between the cuff material and the tracheal tissue. Failure to create an adequate seal increases the probability of subglottic contents leaking around the cuff which enables the pathogenic pathway towards VAP (Gentile & Siobal, 2010). In order to prevent this, researchers have shifted their attention to the cuff material. It has been shown that traditional polyvinyl cuffs are less effective than polyurethane or silicone cuffs. Polyvinyl is thicker than polyurethane or silicone making it more prone to leakage (Deem & Treggiari, 2010). Suctioning subglottic secretions is only beneficial if leakage is prevented. A study conducted by Lorente, Lecyona, Jimenez, Mora, and Sierra (2007) compared polyvinyl cuffed ETTs without subglottic suctioning to polyurethane cuffed ETTs with subglottic suctioning in their ability to prevent VAP. It was shown that the group intubated with the polyurethane ETT set at 20 cmH₂O plus suctioning had significantly reduced incidence rates of VAP when compared to the polyvinyl non suction group ($p < 0.001$) (Lorente et al., 2007). This outcome occurred because the polyurethane cuff isolated secretions above the cuff better than the polyvinyl cuff which allowed subglottic suctioning to remove the secretions instead of allowing them to accumulate with no intervention. It is important to note that suctioning is only effective if secretions are isolated above the cuff. Leakage renders suctioning ineffective in terms of preventing VAP.

In addition to the cuff material, the volume of the cuff plays a role as well. A study done by Young, Pakeerathan, Blunt, and Subramanya (2006) analyzed the difference between low-volume low-pressure (LVLP) and high-volume low-pressure (HVLP) cuffs in their ability to prevent subglottic secretions from being aspirated. It was shown that HVLP cuffs are prone to creating channels through folds in the material where as LVLP cuffs do not have this problem. The inner diameter of the trachea is not large enough to accommodate the volume supplied by a HVLP cuff (Young, Pakeerathan, Blunt, & Subramanya, 2006). Therefore, the cuff never fully inflates resulting in the excess material folding onto itself creating the channels susceptible to fluid leakage. Even with over inflation (cuff pressure greater than 75 cmH₂O) channels still form because of the limited space (Lorente et al., 2007). LVLP cuffs create a sufficient seal allowing subglottic secretions to pool above the cuff and not leak into the lower airway. Young and colleagues (2006) confirmed this when the group intubated with a LVLP cuff reported significantly fewer cases of VAP then the HVLP comparison group (Young et al., 2006).

Even though creating a tight seal is important, care must be taken to not induce tracheal trauma. This can result when the pressure being exerted by the ETT cuff is greater than the perfusion pressure of the tracheal tissue. The American Thoracic Society's guidelines for endotracheal intubation state that the cuff pressure should be maintained between 20-30 cmH₂O in order to prevent subglottic leakage around the cuff (American Thoracic Society & Infectious Diseases Society of America, 2005). It is recommended that the trachea not be subjected to pressures greater than 34 cmH₂O in order to maintain tissue perfusion (Ulrich-Pur et al., 2006). It is important to note that the cuff pressure is not equivalent to tracheal wall pressure. For example, the LVLP cuff must be inflated beyond 45 cmH₂O (33 mmHg) before any constricting

pressure is exerted on the tracheal wall. As discussed earlier, the use of an LVLP cuff is an effective strategy to prevent subglottic secretion aspiration. Therefore, in order to significantly reduce leakage, a LVLP intracuff pressure of 75-80 cmH₂O (55-58 mmHg) would produce a tracheal wall pressure of 25-30 cmH₂O (18-22 mmHg) (Young et al., 2006). The use of a higher intracuff pressure aids in seal formation and in preventing leakage. The intracuff pressure in this example is higher than the traditional 20 cmH₂O, but the important factor is tracheal tissue perfusion was maintained by these parameters and a solid seal was made. This setup satisfies the parameters of both recommendations and enables subglottic secretions to be collected above the cuff and aspirated by the tubes suction lumen.

Secretion Removal

The value of removing subglottic secretions can be determined by comparing incidence rates of VAP between groups receiving or not receiving subglottic suctioning. An analysis study conducted by Dezfulian et al. (2005) followed five randomized controlled trials which enrolled 896 patients who met selection criteria. The patients (435) who received subglottic secretion drainage (SSD) had a reduced incidence rate of VAP (10%) when compared to the control patients (461) who did not receive SSD (20%). In addition, the group receiving SSD had fewer hospital days requiring mechanical ventilation (6.1 ± 2.9) and a decreased ICU length of stay (10.6 ± 5.3) when compared to the control group (7.3 ± 3.8 and 12.5 ± 3.4 respectively). This datum indicates a 50% reduction in VAP when SSD is utilized over standard ETT care (risk ratio: 0.57 with 95% CI: 0.33 to 0.97). Patients receiving SSD were on ventilator support 1.8 days (95% CI: 1.5 to 2.1 days) and in ICUs 1.4 days (95% CI: 0.8 to 2.1 days) shorter than patients not receiving this intervention (Dezfulian et al., 2005).

Viscosity and Volume

The Dezfulian et al. (2005) study illustrates the importance of SSD, but there are several variables inherent to subglottic secretions that can impede the removal process. Variables specific to the secretions themselves are viscosity and volume. With viscosity, secretions that are thin or have a low viscosity are more likely to leak through the cuff channels or avoid suction all together. However, thick or high viscosity secretions may occlude the suction lumen found in certain ETTs (O'Neal, Munro, Grap, & Rausch, 2007). A study conducted by O'Neal, Munro, and Rausch (2007) demonstrated the influence viscosity and volume have in subglottic secretion evacuation. In the study, a Hi-Lo ETT was placed into a tracheal model and specific volumes of secretions were instilled above the cuff and tested individually for evacuation efficiency. The volumes instilled were 2, 4, and 6 mL which were based upon the mean volume (3.5 mL) of secretions recovered from the test sample per hour. The results of the study showed highly viscous secretions to be more evacuable than low viscous secretions. Both viscosities were evacuated more thoroughly when the volume instilled above the cuff was greater. The mean evacuation efficiency of 6 mL of thick secretions was 94% compared to 87% with thin secretions with the suction pressure set continuously at -20 mmHg, the manufacture's recommended setting (O'Neal et al., 2007). Important aspects to recognize with human secretions are their fluid dynamics. The secretions encountered in the subglottic space have viscoelastic non-Newtonian properties. This means that as the concentration of mucus increases so does the viscoelasticity. In addition, the relationship between shear stress and rate of shear on mucus is not linear (Shah, Fung, Brim, & Rubin, 2005). In other words, the viscosity of mucus is highly variable between patients. It seems that patients who are more acutely ill have thicker secretions and therefore

may benefit from a higher suction pressure (O'Neal et al., 2007). Regardless, this concept explains why there is no definitive optimal suction pressure for evacuating subglottic secretions and that thicker secretions are removed more effectively over thinner.

Suction Pressure

The suction pressure by which these secretions are removed is important to consider as well. The goal with suctioning subglottic secretions is finding the balance between efficient secretion removal, maintaining catheter patency, and avoiding tracheal tissue trauma. In other words, determining what pressure to use that will satisfy all three parameters. Previously stated was the point that since secretions are highly variable between patients, there is no optimal suction pressure. To be more specific, there is no suction pressure that will universally meet every patients needs because secretion viscosity and volume are variable. For example, continuous suctioning at -20 mmHg may be effective for one patient but ineffective for another. The reasoning is that one patient may have low volume thin secretions while the other has high volume thick secretions. O'Neal et al. (2007) reported a relationship between suction pressure and secretion volume and thickness. Continuous suction pressures of -20, -30, -40, and -50 mmHg were evaluated against different viscosities of human secretions at varying volumes for evacuation efficiency. The results of the test found -20 mmHg of pressure to be the poorest choice in removing thin or thick secretions at 2, 4, and 6 ml with a mean evacuation percentage of 76% (O'Neal et al., 2007). This is interesting because the evidence-based practice guidelines for VAP prevention recommend a continuous suction pressure of -20 mmHg (Seckel, 2007). The mean value attained from the previous study is important because the practice guidelines do not take into account viscosity or volume. The highest mean evacuation percentage was

delivered by -30 mmHg of pressure when removing thicker secretions. As secretions become thicker, a higher pressure yields a more efficient removal. It is also important to note that as suction pressure increases, thin secretions are evacuated less efficiently than thick. In addition, as the volume above the cuff increases evacuation efficiency increases (O'Neal et al., 2007). Although there is no information available on the number of hospitals that use the Hi-Lo Evac ETT, most studies indicating VAP prevention in their purpose utilize this ETT in their trials (Depew & McCarthy, 2007). The manufacturer of the Hi-Lo Evac recommends continuous suction at -20 mmHg or intermittent suction at -100 to -150 mmHg (Nelcor Puritan Bennett, 2006). Based upon the results of the studies mentioned thus far, -20 mmHg may not be the most effective means of removing subglottic secretions. In addition, the Mujica-Lopez et al. (2010) study previously discussed showed that the subglottic suctioning efficiency of the Hi-Lo Evac is less effective when compared to tubes like the Teleflex ISIS.

Method of Suction

The method of suction is another variable that influences the effectiveness of secretion removal. There are two common methods of suction, intermittent and continuous aspiration. Current VAP prevention guidelines indicate either continuous suctioning at -20 mmHg or intermittent suction at -100 to -150 mmHg to remove subglottic secretions (Seckel, 2007). These guidelines do not detail what type of suctioning should be used based upon patient parameters. The type of suctioning to use depends primarily on the viscosity of secretions and pooled volume. Continuous suctioning is more prone to suction port occlusion due to the combination of lower pressures involved and presence of thick secretions. Thicker secretions are best handled by the 10-15 seconds of intermittent suctioning because of the higher pressures involved

(Mujica-Lopez et al., 2010). There is less conflict when determining what type of suction to apply when secretions are thin because either method can evacuate secretions without occlusion by secretions being a concern. However, a higher pressure may not be adventitious with these secretions. The other major issue to consider with suctioning is tracheal mucosal trauma. If suction is being applied, it should always be evacuating secretions. The risk involved with applying suction with no return is occlusion of the suction lumen by tracheal mucosa resulting in tissue trauma (Berra et al., 2004). Moreover, occlusion of the suction lumen by tissue results in the inability to remove accumulating subglottic secretions which increases the risk of microaspiration. Patients receiving continuous suction are more at risk for this occurring because the vacuum is present regardless of secretion volume. Providing suction only when secretions are present is one of the major advantages of intermittent suctioning. Allowing secretions to accumulate before applying suction avoids the risk of prolonged mucosal occlusion and tissue trauma (Mujica-Lopez et al., 2010). In addition, secretion evacuation is more efficient when suction is applied to a greater pooled volume (O'Neal et al., 2007). It should be noted that there has not been any research done directly comparing continuous and intermittent suction to determine which method is more effective. Subglottic suctioning has shown to decrease VAP with both continuous and intermittent methods of suction, and no one has yet questioned which method is best (Seckel, 2007).

Discussion

The goal of this literature review was to determine the effectiveness of subglottic secretion removal in preventing VAP. It is already known that removing subglottic secretions decreases the incidence of VAP, there has been enough research done to validate that (Smulders, H, Weers-Pothoff, & Vandenbroucke-Grauls, 2002). The inclusion of CASS in the American Thoracic Society VAP prevention guidelines is further proof of its significance in achieving the goal of VAP free critical care units (American Thoracic Society & Infectious Diseases Society of America, 2005). However, there are multiple variables that can adversely affect the positive influence subglottic suctioning has in ventilated patients. This document has covered these variables and identified how to best utilize an ETT with intrinsic suctioning.

ETT with Continuous or Intermittent Suction

Beginning with the tube itself, it was determined that the Teleflex ISIS was a superior tube in the realm of removing secretions when compared to the Hi-Lo Evac due to the increased size of the suction and dorsal lumens. Although no research could be found on the preferred choice of ETTs by hospital systems, most research has been done on the Hi-Lo Evac tube. It may be beneficial for critical care units to explore the possibility of ETTs like the ISIS. An ETT with a suction port that can efficiently clear thin and thick secretions consistently reduces the probability of occlusion.

ETT Cuff Pressure

The next issue is maintaining an appropriate cuff pressure. The cuff is literally the only barrier between the upper and lower airway since the epiglottis has been bypassed to ventilate the patient. A non-occlusive seal can allow secretions to move past the cuff and into the lower

airway resulting in infection. Subglottic suctioning is only beneficial if secretions are not leaking past the cuff. Maintaining an intracuff pressure with respect to tracheal tissue perfusion is critical when establishing a seal. A significant issue with some ETT cuffs is the formation of channels along the length of the cuff. This is the result of the cuff being too large for the airway or having the cuff fold over itself due to thick material. These channels allow small amounts of secretions to leak past the cuff despite using subglottic suction. It was found that LVLP cuffs made of polyurethane limited the formation of complete channels.

Secretion Removal

The dynamics of secretions influence their management and removal. The secretions within the subglottic space may be low or high viscosity and either low or high in volume. These characteristics influence the efficiency of applied suction. The information presented previously showed thicker secretions were cleared better with higher pressures. Secretion removal utilizing low pressure suction may not effectively remove secretions from an efficiency stand point. In addition, the suction port is more susceptible to occlusion utilizing low pressure to remove thick secretions. Intermittent suctioning applies increased suction pressure for short durations. Based on the data reviewed, it is the more logical choice because it can accommodate for viscosity. There is also a decreased risk of suction lumen occlusion by tracheal tissue with this method.

Summary

This integrated review of literature focuses on how subglottic secretion removal is an effective means of reducing the incident rate of VAP. By providing insight on the various aspects of secretions and their management, a better understanding can be drawn on how to best remove subglottic secretions. Research presented in this paper suggests that secretion removal efficiency increases with ETTs that have an increased suction tubing, dorsal lumen, and suction port diameter. When establishing the ETT intracuff pressure, tracheal tissue perfusion should be considered primarily. Using tissue perfusion as the limiter, a better balloon to tissue seal can be made which reduces leakage of subglottic secretions into the lower airway. Monitoring the intracuff pressure is an important nursing intervention since aspiration of contaminated secretions is part of the pathological pathway to VAP. Subglottic secretion management showed importance in the prevention of VAP. By allowing secretions to pool above the cuff and intervening with higher pressure intermittent suctioning, more efficient evacuation was achieved. Taking all these variables into consideration enables subglottic suctioning to be more efficient in preventing VAP by aspiration.

Limitations

A major limitation was the absence of research articles comparing continuous versus intermittent suction with the purpose being which prevents VAP more effectively. This is a major concept and some conclusions in this review on this topic were drawn based off extrapolating data from articles dealing with one or the other.

Research articles experimenting with subglottic fluid dynamics were limited. Only two articles were found that dealt with this concept and only one of them used human secretions (the other used a mucus analog). The limitation is the lack of evidence-based research information on this important topic since it relates to SSD effectiveness and efficiency. It is difficult to draw evidence-based practice conclusions from a small pool of studies.

A limitation related to the research articles used was the sample demographics or no use of human test subjects. The patient population used was confined to a specific unit which deals with a certain patient type. This affects the generalization of research findings. Additionally, a few studies based their research off a human plastic model, animal analog, or cadavers. This is a limitation because only theoretical conclusions can be made since the experiment was not performed on a human subject.

Recommendations for Nursing

Research

Although the concept of subglottic suctioning has been researched extensively, this review has shown where gaps in current research exist and what topics could benefit from additional focused research. There is currently no data available on the preferred or most commonly used ETT in hospitals nationally. Although the subglottic suction ETT is recommended in clinical practice guidelines, it is not known how many institutions actually adhere to this recommendation.

There is limited research directly comparing continuous to intermittent suctioning with the purpose of determining which removes subglottic secretions more effectively given the variability inherent to all secretions. The research presented in this review suggests intermittent suction is more beneficial in removing secretions. However, a study that uses both methods of suction, with the same secretion evacuation experiments, and the same tracheal model would provide more conclusive results.

It is known that subglottic suctioning can cause tracheal trauma if the tissue membrane is sucked into the suction port. It is suggested by this review that -30 mmHg of continuous suction is more beneficial than the guideline recommended -20 mmHg. However, there is little research available that explores the effects of -30 mmHg on tracheal tissue during and after intubation. That pressure may prove to cause more harm than good. Limited research is available on the incidence rate or long term complications of tracheal erosion secondary to subglottic suctioning.

Additional research on the concept of intracuff pressure and its relation to tracheal ischemia, edema, and erosion would be beneficial. Although it is known that over inflating the

cuff results tracheal edema post extubation (Berra et al., 2004), there is limited research regarding intracuff pressure and establishing a balloon-tissue seal with respect to tissue perfusion. The study identified in this review experiments with this concept but more research would be beneficial.

Research related to different cuff shapes, their position in the trachea, and suction port location needs to be conducted. ETT developers are now experimenting with different cuff materials and shapes that contrast to the traditional polyvinyl oval balloon. Changes in the volume of secretions that accumulate above the cuff and therefore the amount available for suctioning are possible beneficial insights. Experimenting with the suction port, especially placement, could yield outcomes that benefit subglottic secretion removal efficiency.

Education

Critical care nurses should adhere to the VAP prevention guidelines established by their institution. Although this review focuses exclusively on subglottic secretions and their removal to prevent VAP, there are other equally important interventions that need to be done to prevent VAP. The evidence-based practices made available to nurses through this review may enhance their VAP preventative care. It may also serve as a reminder of proper care and be a means to fill gaps in knowledge. In a study conducted by Cason, Tyner, Saunders, and Broome (2007), out of 1200 critical nurses surveyed, only 36% reported using subglottic suctioning as a preventative strategy against VAP (32% reported it as a respiratory therapy intervention) (Cason et al., 2007). This statistic raises concern because at best subglottic suctioning is used 68% of the time with combined efforts from nurses and respiratory therapists. Nursing adherence to practice guidelines is questionable and may not be implemented consistently (Sole, Byers, Ludy, &

Ostrow, 2002). In addition to the other interventions that reduce VAP, nurses need to be educated on current guidelines and notified when changes are made since nursing practice evolves over time. Policy, procedures, and unit information regarding VAP and its prevention need to be made available to nurses. The gap between what nurses know and how they practice may shrink if VAP care protocols are made accessible on the unit (Cason et al., 2007).

Clinical Practice

An important point presented in this paper was the concept of secretion management in conjunction with subglottic suctioning. Critical care nurses should consider analyzing the viscosity and volume of secretions being put out by their patient routinely. It may be beneficial to allow secretions to accumulate above the cuff. Although it sounds counterintuitive based on current research, allowing 4-6 mL of secretions to pool above the cuff may promote more efficient removal. Thicker secretions are best handled by higher suction pressures provided by intermittent suctioning. Intermittent suctioning also reduces the risk of catheter occlusion and allows for secretions to gather allowing for more efficient removal. However, intermittent suction requires the nurse to monitor suction frequency more closely. If continuous suctioning is used as an alternative, -30 mmHg may be more beneficial than the standard -20 mmHg because variances in secretion viscosity and volume are better handled by this pressure. Additionally, it may be beneficial to apply more suction in patients who are more acutely ill because secretions tend to thicken as acuity increases. Damage to the tracheal mucosa is a risk associated with continuous suctioning and -30 mmHg of pressure may increase this risk (O'Neal et al., 2007). Continuous monitoring of the ETT cuff pressure is a recommended intervention. Maintaining an ETT cuff pressure within a target range (20-30 cmH₂O) reduces the risk of secretions leaking

around the cuff with under inflation and tracheal trauma from over inflation (Sole et al., 2011). Although further research needs to be done, inflating a LVLP cuff to 75-80 cmH₂O (55-58 mmHg) produces a tracheal wall pressure of 25-30 cmH₂O (18-22 mmHg). Tracheal perfusion begins to decrease when the tissue is subjected to pressures exceeding 34 cmH₂O (Young et al., 2006). Therefore it may be more beneficial to increase the intracuff pressure above the standard to produce a better seal without sacrificing perfusion. Taking these factors into consideration will guide the nurse in choosing the most appropriate method and frequency of suction.

Appendix A

Table

Appendix A: Table

Table 1

Table of Evidence by study design:

Survey					
Article	Participants and Study Design	Intervention Details	Outcome Measures	Results/Key Findings	Relevance/Implications
Cason, C. L., Tyner, T., Saunders, S., & Broome, L. (2007). Nurses' implementation of guidelines for ventilator-associated pneumonia from the centers for disease control and prevention. <i>American Journal of Critical Care, 16</i> (1), 28-38.	1200 critical care nurses Survey	A 29 question survey was administered to critical care nurses attending education seminars to assess their knowledge on the type and frequency of preventative VAP care.	Completed surveys were scanned into a computer and the information was compiled. Using SPSS for Windows, the characteristics of responses from those surveyed could be rendered.	1285 surveys out of 1596 distributed were returned. 85 were discarded leaving 1200 critical care nurse respondents. VAP prevention guidelines are not consistently adhered to which increases the risk of VAP due to nurse incompetence.	This information highlights the importance of educating critical care nurses on the unit to reinforce prevention guidelines. The standard of care is set high but nurses are not meeting those standards based upon the results of the survey.

Labeau, S., Vandijck, D. M., Claes, B., van Aken, P., & Blot, S. I. (2007). Critical care nurses' knowledge of evidence-based guidelines for preventing ventilator-associated pneumonia: An evaluation questionnaire. <i>American Journal of Critical Care, 16</i> (4), 371-377.	638 critical care nurses evaluated. Survey	10 questions were derived from VAP prevention guidelines focusing on appropriate nurse intervention.	Validity, accuracy, and difficulty of the questions asked. In addition, assessment of correct responses to determine knowledge gap.	Nine out of the ten questions administered were deemed valid for the purpose of the questionnaire. The results showed an apparent gap on knowledge regarding VAP prevention interventions.	The gap in knowledge regarding proper VAP prevention interventions identifies a need for reeducating critical care nurses.
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Literature Review					
Article	Participants and Study Design	Intervention Details	Outcome Measures	Results/Key Findings	Relevance/Implications
Depew, C. L., & McCarthy, M. S. (2007). Subglottic secretion drainage: A literature review. <i>AACN Advanced Critical Care, 18</i> (4), 366-379. doi:10.1097/01.AACN.0000298629.15159.04	Literature review	None Specified. Literature review.	The availability of credible research that supports the use of endotracheal tubes with subglottic suction to prevent VAP.	Based upon analysis of research articles discussing this concept, the use of endotracheal tubes that can remove subglottic secretions by means of a separate suction port does help reduce the incidence of VAP. The article suggests further research needs to be done on the subject.	The research articles reviewed in this article provide an excellent overview of the topic being discussed in this review. It confirms the importance of using CASS to prevent the onset of VAP in critically ill patients. In addition, the article describes the importance of defined protocol on units to eliminate uncertainty in preventative care.

<p>Pneumatikos I. A., Dragoumanis C. K., & Bouros D. E. (2009). Ventilator-associated pneumonia or endotracheal tube-associated pneumonia?: An approach to the pathogenesis and preventive strategies emphasizing the importance of endotracheal tube. <i>Anesthesiology</i>, 110(3), 673. doi:10.1097/ALN.0b013e31819868e0</p>	<p>No patient involvement.</p> <p>Literature review of randomized controlled trials, observational studies, literature reviews, meta-analyses, and case reports that met required strength parameters.</p>	<p>Reviewed the impact of the subglottic suction, controlled intracuff pressure, preventing channel formation and leakage, decontamination of the subglottic space, and preventing and removing tube biofilm.</p>	<p>Outcomes are based on whether a recommendation is effective at preventing VAP in terms of incidence rate.</p>	<p>Subglottic suctioning decreases the incidence rate of VAP. Maintaining intracuff pressure within the recommended 20-30 cmH₂O interval aids in avoiding aspiration.</p>	<p>There are several practices explored in this article that do not fit the scope of this review. However, for those that did they were found to be an effective means of reducing the incidence rate of VAP. Subglottic suctioning paired with a good cuff seal decrease the probability of microaspiration.</p>
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Meta Analysis					
Article	Participants and Study Design	Intervention Details	Outcome Measures	Results/Key Findings	Relevance/Implications
<p>Dezfulian, C., Shojania, K., Collard, H. R., Kim, H. M., Matthay, M. A., & Saint, S. (2005). Subglottic secretion drainage for preventing ventilator-associated pneumonia: A meta-analysis. <i>The American Journal of Medicine</i>, 118(1), 11-18. doi:10.1016/j.amjmed.2004.07.051</p>	<p>896 patients pooled between five research studies.</p> <p>Meta-analysis</p>	<p>Computerized database search of research articles pertaining to efficacy of subglottic suctioning in preventing VAP.</p>	<p>Availability of credible research that defined the risk of VAP in mechanically ventilated patients. In addition, the effects of subglottic secretion drainage related to incidence rate of VAP, hospital length of stay, and mechanical ventilation days.</p>	<p>The use of subglottic secretion drainage reduces the risk of VAP, decreases hospital length of stay, and duration of mechanical ventilation. It is a cost effective method of preventing VAP.</p>	<p>This article combines five relevant research studies for the purpose of this review. Benefits and risks of SSD are defined. In addition, cost effectiveness of the intervention is provided. Subglottic suctioning is an effective means of reducing the incidence rate of VAP is used effectively.</p>

Systematic Review					
Article	Participants and Study Design	Intervention Details	Outcome Measures	Results/Key Findings	Relevance/Implications
Gentile, M. A., & Siobal, M. S. (2010). Are specialized endotracheal tubes and heat-and-moisture exchangers cost-effective in preventing ventilator associated pneumonia? <i>Respiratory Care</i> , 55(2), 184-96.	No patient involvement. Systematic review of randomized controlled clinical trials and meta analysis' that satisfied degree of confidence parameters.	None specified. Systematic review	A decrease in VAP with the use of CASS enabled ETTs, polyurethane cuffs, silver-coated ETTs, and heat and moisture exchangers.	CASS enabled ETTs show a reduction in VAP when used effectively. Silver-coated ETTs and polyurethane cuffs show promise in preventing the onset of VAP. Heat and moisture exchangers may be a cost effective alternative to humidifiers but are associated with adverse effects.	The information covering silver-coated ETTs and heat and moisture exchangers is relevant for preventing VAP but does not fit the criteria for this review. However, CASS ETTs preventing VAP and the use of polyurethane cuffs to form a better cuff-tissue seal does fit the scope of this review. These are two important concepts for critical care nurses to realize. The first is realizing that a patent subglottic suction line is necessary for it to be effective. The second is the importance of maintaining an appropriate intracuff pressure to not allow leakage.

Descriptive Study					
Article	Participants and Study Design	Intervention Details	Outcome Measures	Results/Key Findings	Relevance/Implications
Mujica-Lopez, K. I., Pearce, M. A., Narron, K. A., Perez, J., & Rubin, B. K. (2010). In vitro evaluation of endotracheal tubes with intrinsic suction. <i>Chest</i> , 138(4), 863-869. doi:10.1378/chest.09-3117	No patient involvement. Descriptive study	Three CASS-ETT's were evaluated for their effectiveness at removing subglottic secretions. Continuous and intermittent suction were evaluated against secretions of varying volume and viscosity. Tracheal membrane occlusion prevention.	Determining which ETT is preferred by evaluating their secretion removal efficiency, occlusion risk, and tracheal trauma risk.	The diameter of the ISIS ETT's suctioning tubing is greater than the competition, which makes it more effective at removing secretions, less prone to occlusion by secretions, but more prone to occlusion by tracheal tissue. Intermittent suctioning is more effective at removing thick secretions than continuous.	Complications associated with subglottic suctioning are occlusion of the suction port by secretions or tissue. This study emphasizes the importance of monitoring for both of these complications. Intermittent suctioning appears to be more beneficial than continuous since it is less prone to occlusion.
O'Neal, P. V., Munro, C. L., Grap, M. J., & Rausch, S. M. (2007). Subglottic secretion viscosity and evacuation efficiency. <i>Biological Research for Nursing</i> , 8(3), 202-209. doi:10.1177/1099800406295517	Subglottic secretions here harvested from 32 mechanically ventilated patients. Descriptive study	Laboratory tracheal model was used to simulate an intubated human patient. The secretions harvested from patients were instilled in 2, 4, and 6 mL of varying viscosity above the cuff. Variable suction pressures were applied to the instillations.	Determine the most effective suction pressure for removing subglottic secretions of differing pooled volumes and viscosity.	Thicker secretions of greater volume were more evacuated more thoroughly than thinner low volume secretions. In general, thick secretions of any volume are more efficiently removed (using higher pressure) than thinner secretions at standard suction pressure.	This is a critical concept when reviewing the effectiveness of subglottic suctioning. It may be more beneficial to allow secretions to pool slightly above the cuff and apply intermittent suction to evacuate them.

Shah, S., Fung, K., Brim, S., & Rubin, B. K. (2005). An in vitro evaluation of the effectiveness of endotracheal suction catheters. <i>Chest</i> , 128(5), 3699-3704. doi:10.1378/chest.128.5.3699	No patient involvement. Descriptive study.	Mucus stimulants with varying viscoelastic properties were used to test suction effectiveness of varying endotracheal catheters.	By comparing which catheter removed secretions more efficiently determined the best choice.	The greater the airflow or suction the more mucus can be suctioned within a defined period of time. Therefore, the catheter with the biggest port will suction more secretions given the appropriate suction force applied.	The purpose of this article is not relevant to this review. However, the concepts identified within it are. The focus of this article is on how the fluid dynamics of mucus affects the ability to suction and how suction port size increases or decreases the efficiency of suction. These concepts are relevant in terms of subglottic secretions and the suction pressure applied through the ETT suction port.
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Clinical Trials					
Article	Participants and Study Design	Intervention Details	Outcome Measures	Results/Key Findings	Relevance/Implications
Lorente, L., Lecuona, M., Jimenez, A., Mora, M. L., & Sierra, A. (2007). Influence of an endotracheal tube with polyurethane cuff and subglottic secretion drainage on pneumonia. <i>American Journal of Respiratory and Critical Care Medicine</i> , 176(11), 1079-1083. doi:10.1164/rccm.2007.05-761OC	280 patients who were expected to be on mechanical ventilation greater than 24 hours who were older than 18 years of age, not pregnant, and not immunodeficient. Clinical randomized controlled trial.	Patients were randomly assigned to one of two groups. One group utilized a conventional ETT while the other used polyurethane cuffed CASS enabled ETT.	Compare the incidence rate of VAP between the two groups to determine if the variables (polyurethane cuff and CASS) played a role in VAP prevention.	The group utilizing the specialized ETT had significantly less cases of VAP than the group using the conventional ETT.	Subglottic suctioning decreases the incidence rate of VAP in the mechanically ventilated patient. However, suctioning is ineffective if secretions are able to leak around the cuff. The use of a polyurethane cuff makes for a better seal and reduces channel formation and, therefore, leakage.

<p>Sole, M. L., Su, X., Talbert, S., Penoyer, D. A., Kalita, S., Jimenez, E., . . . Bennett, M. (2011). Evaluation of an intervention to maintain endotracheal tube cuff pressure within therapeutic range. <i>American Journal of Critical Care : An Official Publication, American Association of Critical-Care Nurses</i>, 20(2), 109-118. doi:10.4037/ajcc2011661</p>	<p>32 mechanically ventilated patients from varying critical care units.</p> <p>Randomized, repeated-measures crossover design</p>	<p>Registered nurses who doubled as study personal maintained an intracuff pressure of 22 cmH₂O on all test subjects. Cuff pressure alarms were used to queue nurses when air needed to be removed or added to the cuff to maintain the desired study pressure.</p>	<p>End points assessed were the frequency the ETT cuffs being used triggered an alarm indicating too low (less than 20 cmH₂O) or too high of an intracuff pressure (greater than 30 cmH₂O) and how intervention affected cuff pressure variability.</p>	<p>27 patients yielded usable results. It was found that continuous monitoring of ETT cuff pressure was effective at maintaining a desired intracuff pressure. Patients receiving this intervention had a more stable pressure with fewer fluctuations. Additionally, cuff pressure was found to decrease over time which required intervention near the end of a 12 hour shift.</p>	<p>A solid cuff-tissue seal makes subglottic suctioning more effective. If secretions are able to leak past the cuff then suctioning is useless from a preventative standpoint. This study shows that it is reasonable for nurses to monitor their patients cuff pressure to ensure an adequate seal.</p>
<p>Ulrich-Pur, H., Hrska, F., Krafft, P., Friehs, H., Wulkersdorfer, B., Köstler, W., . . . Frass, M. (2006). Comparison of mucosal pressures induced by cuffs of different airway devices. <i>Anesthesiology</i>, 104(5), 933-938.</p>	<p>19 cadavers less than 24 hours postmortem who were not previously intubated or resuscitated.</p> <p>Clinical randomized controlled trial</p>	<p>One of seven possible airway devices was inserted into each cadaver. Which device was randomized and every device was placed. A microchip was placed appropriately for each cuff to measure pressure exerted on the trachea.</p>	<p>Goal was to determine the appropriate pressure for each device using the pressure exerted on the trachea as the limiter.</p>	<p>As cuff volume increases, so does the pressure exerted on the tracheal wall.</p>	<p>One of the airway devices used was the convention ETT which began showing high tracheal pressure when the intracuff pressure measured 41 cmH₂O. The significance with this result is higher cuff pressures can be used to make firmer seals without causing tracheal trauma.</p>

<p>Young, P. J., Pakeerathan, S., Blunt, M. C., & Subramanya, S. (2006). A low-volume, low-pressure tracheal tube cuff reduces pulmonary aspiration. <i>Critical Care Medicine</i>, 34(3), 632-639.</p>	<p>38 anesthetized and 67 critically ill patients.</p> <p>Prospective, randomized controlled clinical study, observational study</p>	<p>LVLVP cuff was compared to the HVLP cuff for leakage using dye as the subglottic secretion substitute in both a rigid and pig tracheal model.</p>	<p>The degree of leakage around the cuff before and after movement in both models when comparing LVLVP to HVLP.</p>	<p>LVLVP cuffs reduce leakage when compared to HVLP.</p>	<p>Aspiration of subglottic secretions is a major risk factor in the development of VAP. The use of ETTs with a LVLVP would form a more reliable seal allowing subglottic suctioning to be effective. The Hi-Lo Evac is again shown to not be a reliable choice due to occlusion issues which prevents secretion removal despite an adequate cuff-tissue seal.</p>
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Appendix B

Figures

Appendix B: Figures

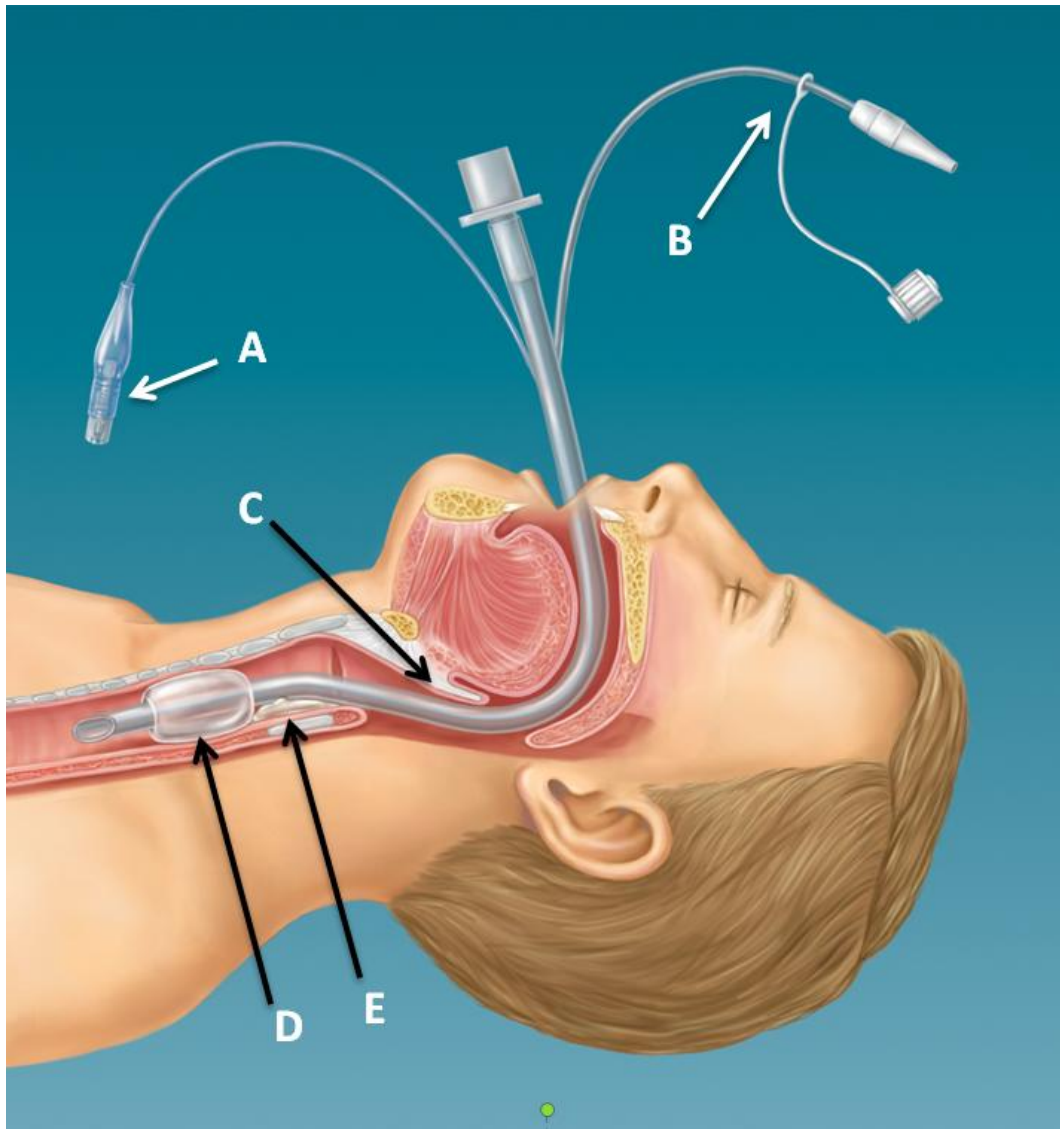


Figure 1. Graphical representation of endotracheal tube placement and function. Hi-Lo Evac endotracheal tube illustrated. A: line for inflating/deflating cuff; B: line for aspiration of subglottic secretions; C: epiglottis; D: ETT cuff/balloon; and E: region where subglottic secretions pool and location of dorsal CASS orifice. Image used by permission from Nellcor Puritan Bennett LLC, Boulder, Colorado, doing business as Covidien.

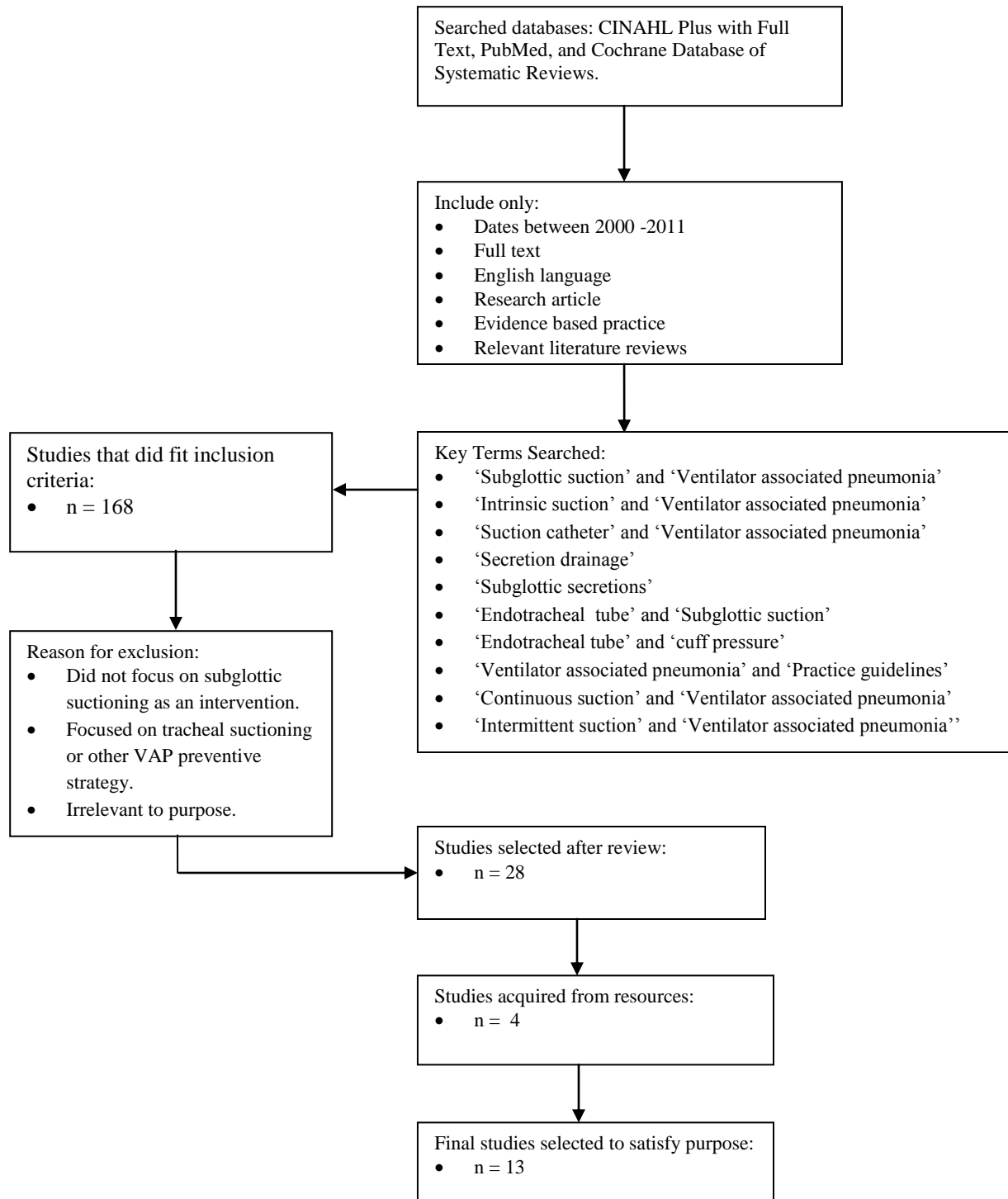


Figure 2. Flow model for literature selection

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