New Endotracheal Tubes Designed to Prevent Ventilator-Associated Pneumonia: Do They Make a Difference?

Steven Deem MD and Miriam M Treggiari MD PhD MPH

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Summary

Ventilator-associated pneumonia (VAP) is a pervasive and expensive nosocomial infection that is largely related to instrumentation of the airway with an endotracheal tube (ETT), followed by microaspiration of contaminated secretions. VAP prevention will probably be most effective via a multifaceted approach, which includes meticulous attention to basic infection-control methods during patient care, proper patient positioning, oral hygiene, and removal of the ETT as soon as indicated. Modification of the ETT to reduce microaspiration and/or biofilm formation may also play an important role in VAP prevention. However, despite numerous studies of various such interventions, there is insufficient evidence upon which to base strong recommendations, and important safety concerns remain regarding the use of some devices. Most importantly, cost-effectiveness data are lacking for modified ETTs designed to prevent VAP. It is critical that future studies of ETTs designed to prevent VAP be adequately powered to demonstrate efficacy on important patient outcomes and safety, in addition to cost-effectiveness. Key words: nosocomial pneumonia; infection; subglottic; endotracheal tube; ventilator-associated pneumonia; VAP; mortality; morbidity. [Respir Care 2010;55(8):1046–1055. © 2010 Daedalus Enterprises]

Introduction

Nosocomial pneumonia is a common complication in critically ill patients. A large multicenter study conducted in European intensive care units (ICUs) and involving more than 10,000 patients identified pneumonia as by far the most common nosocomial infection, with an overall prev-

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alence of 10%. Mechanical ventilation has been consistently identified as the greatest risk factor for the development of nosocomial pneumonia. Indeed, ventilator-associated pneumonia (VAP) accounts for 80–90% of cases of nosocomial pneumonia in ICU patients. This observation is probably due to factors associated with translaryngeal intubation rather than simply an effect of patient susceptibility from severity of illness (see below under “Pathogenesis”). The quoted incidence of VAP ranges widely, between 5% and 67%, depending on the patient population studied and the diagnostic criteria used. The 6 largest studies, involving a mixed population of more than 5,500 patients and a variety of diagnostic techniques, identified VAP incidences between 9% and 28%. The risk of VAP is highest in the first few days of intubation, with a daily hazard rate of approximately 3% at day 5 of intubation, decreasing to 1% per day by day 15. Cumulative risk continues to accrue for the duration of mechanical ventilation.

VAP appears to be independently associated with increased morbidity, as measured by increased duration of mechanical ventilation, ICU stay, and hospital stay. A retrospective analysis of 4,543 patients at 59 United States hospitals found that mortality associated with VAP was 29%, compared to 19% and 10% for hospital-acquired and community-acquired pneumonia, respectively. In the largest studies that reported mortality, the mortality figures associated with VAP ranged from 24% to 54%. Because the likelihood of VAP also increases with severity of illness, the mortality attributable to VAP is difficult to separate from the mortality related to other aspects of the patient’s illness. Studies using case-control design suggest that the mortality attributable to VAP is between 15% and 48%, and may be higher in the presence of multiple-drug-resistant pathogens. The increased intensity and duration of care for patients with VAP is also associated with increased cost of care. Papazian et al observed that the incremental costs associated with VAP were generated even in the absence of significantly increased duration of mechanical ventilation, ICU stay, or hospital stay. A conservative estimate of the increased costs due to VAP, using matched controls and based on an average increased stay of 10 days, was approximately $12,000 (inflation-adjusted to 1992 United States dollars). A more recent study found that hospital charges were $48,500 (inflation-adjusted to 1996 United States dollars) greater in patients with VAP, compared to matched controls.

Several strategies to prevent VAP have been investigated, and are reviewed in depth elsewhere. Prevention of VAP has focused primarily on:

- Improvement of pulmonary secretion clearance by rotational therapy
- Prevention of microaspiration of oropharyngeal contents by semi-recumbent positioning
- Prevention of microaspiration via alterations in ETT design
- Prevention of ETT bacterial colonization by coating the ETT lumen with silver chloride

Several approaches have been found promising, but are associated with measurable or potential costs. The remainder of this review will focus on the role of the ETT in the pathogenesis of VAP, and how modification of the ETT may help prevent VAP.

**Pathogenesis of Ventilator-Associated Pneumonia: The Role of the Endotracheal Tube**

A compelling argument can be made that it is the ETT, and not the ventilator, that increases susceptibility to pneumonia in ICU patients. Placement and maintenance of a tube through the glottis predisposes to nosocomial pneumonia via several possible mechanisms:

- Aspiration of oropharyngeal secretions during tracheal intubation, as illustrated by the increased risk of VAP associated with re-intubation
- Trauma and mechanical forces on the tracheal wall that decrease mucosal integrity and reduce mucociliary clearance of secretions
- Microaspiration of secretions around the inflated ETT cuff
- Biofilm formation and bacterial colonization inside the ETT lumen.

The following discussion will focus on microaspiration, biofilm formation, and colonization.

VAP appears to be preceded by bacterial colonization of the trachea in most cases. The major source of colonization is probably contaminated oropharyngeal secretions that leak through folds of the inflated ETT cuff into the trachea. Microaspiration occurs in virtually 100% of inflated high-volume, low-pressure ETT cuffs. Microaspiration is reduced but still present in the semi-recumbent, compared to the supine, position. Oropharyngeal bacterial colonization increases the risk of developing VAP, and there is concordance between oropharyngeal colonizing flora and the causative organisms of VAP, as diagnosed by invasive techniques. Furthermore, interventions that reduce oropharyngeal colonization (topical oropharyngeal antiseptics, selective digestive decontamination) or reduce tracheal microaspiration have been found promising, but are associated with measurable or potential costs. The remainder of this review will focus on the role of the ETT in the pathogenesis of VAP, and how modification of the ETT may help prevent VAP.

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tion (semirecumbent positioning) reduce the incidence of VAP.\textsuperscript{27-29,31,36}

Another way the ETT may contribute to VAP is through bacterial colonization and subsequent biofilm formation in the lumen of the tube. This process occurs within a few days of tracheal intubation, and there is remarkable concordance between the organisms within the biofilm and tracheal-suctioning samples from patients with VAP.\textsuperscript{49,50}

A biofilm is a structured community of bacterial cells in a self-produced polymeric matrix and adherent to an inert or living surface.\textsuperscript{51} Biofilms appear to confer resistance to antibiotics by creating a microenvironment that favors bacterial proliferation and makes the bacteria inaccessible to antimicrobials.\textsuperscript{52} A biofilm adhering to the surface of the ETT may act as a continuous source of bacterial contamination of the lower respiratory tract. On the other hand, the ETT appears to become colonized with bacteria after the lower respiratory tract.\textsuperscript{42} This observation suggests that microaspiration of contaminated secretions may be the primary event in the causal pathway for VAP, but that biofilm formation plays a role in maintaining tracheal bacterial colonization.

Strategies for Preventing Ventilator-Associated Pneumonia

Considering the mechanisms leading to VAP, it would appear that efforts to reduce microaspiration of contaminated secretions and biofilm formation within the ETT lumen would be beneficial in preventing VAP. One obvious approach to prevention of VAP is to avoid instrumentation of the airway by using noninvasive ventilation when appropriate. A meta-analysis by Hess found that the use of noninvasive ventilation conferred a reduction in the relative risk of VAP of 76–85%, in comparison with invasive mechanical ventilation.\textsuperscript{53} A recent analysis of over 6,000 cases of nosocomial pneumonia from 400 German hospitals found a nearly 5-fold increase in the mean incidence density of pneumonia in patients undergoing invasive ventilation, compared to noninvasive ventilation.\textsuperscript{54} These data further support the role of airway violation by the ETT in the causal pathway for VAP.

In terms of other interventions to minimize microaspiration and airway colonization, limited evidence suggests that reduction of microaspiration by using semi-recumbent positioning reduces the risk of VAP\textsuperscript{36,55,56}; likewise, decontamination of the oropharynx with topical chlorhexidine may also reduce the risk of VAP.\textsuperscript{51} However, given that neither of these interventions has been conclusively shown to prevent VAP, alternative and/or multi-modality approaches could further minimize the risk of VAP. The following section reviews modifications of the design of the ETT that aim to reduce microaspiration, and a variety of techniques designed to limit biofilm formation on the lumen of the ETT (Table 1).\textsuperscript{57-65}

Continuous Suctioning of Subglottic Secretions

One innovation in ETT design is the placement of an orifice just above the tube cuff, connected to an externalized lumen that allows intermittent or continuous suctioning of subglottic secretions (Fig. 1).\textsuperscript{57} The principle behind this technique is that secretions pool in the space between the laryngeal aperture and the ETT cuff, and that removal of these secretions may prevent or minimize microaspiration, tracheal colonization with bacteria, and ultimately VAP. Nine randomized trials and one prospective observational trial have investigated ETTs that allow subglottic suctioning.\textsuperscript{38,60,66-72} Suction was applied continuously or intermittently via the suction port to remove subglottic secretions. A meta-analysis examined the data from five of these studies and estimated that subglottic suctioning gave an approximately 50% overall reduction in the risk of VAP, based on the pooled results (relative risk 0.51, 95% CI 0.37–0.71).\textsuperscript{57} The time to onset of VAP was delayed by 3.1 days (95% CI 2.7–3.4) with the use of subglottic suctioning. When examined on an intention-to-treat basis, the relative risk of death in patients receiving subglottic suctioning from the 4 studies reporting mortality was 1.13 (95% CI 1.04–1.53).\textsuperscript{67-70} Likewise, there were no significant effects of subglottic suctioning on duration of mechanical ventilation, ICU stay, or hospital stay. However, when per-protocol analysis was performed, there were significant reductions in duration of mechanical ventilation and ICU stay.

Of the remaining studies investigating the role of subglottic suctioning in VAP prevention, one small randomized trial published only in the Chinese language reported a significant reduction in VAP, duration of mechanical ventilation, and ICU stay in association with the intervention.\textsuperscript{71} Another small randomized trial found a significant reduction in VAP in patients who were intubated with a polyurethane-cuffed subglottic-suctioning ETT, but no effect on other outcomes.\textsuperscript{60} A third small trial found no effect of subglottic suctioning on tracheal bacterial colonization or VAP,\textsuperscript{73} and a prospective, observational study of 250 patients found no effect of subglottic suctioning on the risk of VAP.\textsuperscript{72}

The largest single study of subglottic suctioning to prevent VAP randomized 740 patients undergoing major cardiac surgery to intubation with a subglottic-suctioning ETT and continuous subglottic suctioning in the ICU, versus intubation with a conventional ETT.\textsuperscript{38} The subglottic-suctioning ETT did not reduce the incidence of VAP or the duration of mechanical ventilation, ICU stay, hospital stay, or mortality. The subglottic-suctioning ETT was associ-
ated with less antibiotic use and less VAP in a subset of the population intubated for more than 48 hours.

Based on the literature reviewed above, there is no clear evidence about the efficacy and effectiveness of subglottic suctioning in reducing the development of VAP. Moreover, there are several limitations in the data from the randomized trials that reduce their strength and generalizability:

Patient Selection and Lack of Intention-to-Treat Analysis. Each of the studies that have shown a significant effect of subglottic suctioning selected patients who were expected to require mechanical ventilation for 2–3 days or more, and yet the criteria for making that determination were not explicit in any study. In 2 studies, patients who were ventilated less than 3 days were excluded from analysis, invalidating the randomization process. The lack of intention-to-treat analysis and vagaries in study selection process limits the ability to make inference to a larger, mixed population of patients requiring emergency tracheal intubation with no knowledge of the anticipated duration of ventilation.

Practically, it is difficult to introduce a device into practice when the criteria for patient selection and identification of the target population likely to benefit from the intervention are not explicit. In practice, it is often difficult to predict duration of ventilation at the time of intubation in the emergency setting. Approximately 60% of the variability in duration of mechanical ventilation is explained by patient characteristics, and duration of ventilation can be at least in part predicted using multiple logistic regression techniques. Therefore, it is likely that practical implementation of subglottic suctioning would require insertion of the subglottic-suctioning ETT in an unselected population of patients requiring mechanical ventilation of

<table>
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<tr>
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<td>Appears to reduce early-onset VAP, but cost-effectiveness and safety not clear.</td>
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<td>Microcuff</td>
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<td>Limited data suggest less short-term microaspiration, but effect on VAP not clear.</td>
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<tr>
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<td>One RCT showed efficacy in preventing VAP, but cost-effectiveness and safety not clear. High acquisition cost.</td>
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<tr>
<td>Mucus Slurper</td>
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<td>Prevents mucus buildup in vitro, but no published clinical data</td>
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<td>Mucus Shaver</td>
<td>Inflatable silicone-rubber “razor” to remove mucus and biofilm from endotracheal tube lumen</td>
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VAP = ventilator-associated pneumonia  
RCT = randomized controlled trial
variable duration. A large-scale implementation of tracheal intubation with subglottic-suctioning-equipped ETTs has not been proven efficacious. Additionally, inefficiencies associated with widespread insertion of the subglottic-suctioning ETT may reduce the cost-effectiveness of the device (see discussion below).

Lack of Application of Other Strategies to Reduce VAP. None of the positive studies of subglottic suctioning systematically applied concomitant strategies known to reduce the risk of microaspiration and VAP, such as semi-recumbent positioning.

Lack of Cost-Effectiveness Data. In addition to the methodological issues and limitations in the available studies, the cost related to subglottic suctioning has not been adequately addressed by previous investigations.

Safety Concerns Associated With the Subglottic-Suctioning ETT. Important safety concerns regarding the use of the subglottic-suctioning ETT and subglottic suctioning exist. Subglottic suctioning may lead to mucosal drying and trauma and thus predispose the airway to injury more than intubation with a conventional ETT, as demonstrated in a recent in vivo study. Sheep that were intubated with a subglottic-suctioning ETT and subjected to continuous subglottic suctioning and mechanical ventilation for 3 days all exhibited severe tracheal mucosal injury, including necrosis and exposure of tracheal cartilage. Animals intubated with a conventional ETT had no tracheal injury. A recent clinical study raises additional concerns about the potential for subglottic suctioning to cause tracheal injury; in 17 (43%) of 40 patients undergoing subglottic suctioning who were evaluated endoscopically, herniation of the tracheal mucosa into the subglottic suctioning lumen was evident.

Another concern is that in order to maintain competency of the suction lumen the subglottic-suctioning ETT is thicker and more rigid than conventional ETTs, which may lead to an increase in airway-related complications. The outside diameter of a 7.5-mm inner-diameter subglottic-suctioning ETT (Hi-Lo Evac, Mallinckrodt, St Louis, Missouri) is approximately 1 mm greater than that of a conventional tube with the same inner diameter. This is concerning, given that increasing tube size is a risk factor for pharyngeal and laryngeal injury. A case report described the occurrence of a tracheal-innominate artery fistula associated with use of a Hi-Lo Evac Tube, following which the authors confirmed the increased rigidity of the tube in a bench model.

Complications related to the subglottic-suctioning ETT were not mentioned in 6 of the 9 prospective randomized trials of subglottic suctioning. In 2 trials the absence of complications was reported, but in those trials the duration of mechanical ventilation was relatively short. It is not clear if airway complications were systematically sought in these or any of the other trials. However, concern regarding the safety of the subglottic-suctioning ETT and subglottic suctioning was raised in the study by Girou et al, who reported laryngeal edema requiring re-intubation in an exceedingly high proportion (25%) of patients undergoing subglottic suctioning. This compares to an incidence of re-intubation due to stridor and upper-airway obstruction of approximately 1–2% when conventional tubes are used.

It is conceivable that the limited benefit of subglottic suctioning on duration of mechanical ventilation, stay, and mortality in prospective trials might be due to an increased incidence of airway-related complications that result in the need for re-intubation or prolonged intubation that offset the benefits of preventing VAP. Future trials should include more systematic evaluation of safety issues associated with subglottic suctioning and the subglottic-suctioning ETT.

Given the above discussion, it is evident that there are insufficient efficacy data and concerns regarding the safety of subglottic suctioning and the subglottic-suctioning ETT; these concerns warrant caution in widely deploying this intervention for the prevention of VAP. Despite this apprehension, both the Center for Disease Control (Level II recommendation) and the American Thoracic Society (Level I recommendation) recommend subglottic suctioning of tracheal secretions as a VAP-preventive measure.

Polyurethane-Cuffed Endotracheal Tubes

Recently, efforts have focused on modifying the ETT cuff composition and design to prevent channel formation within the inflated cuff and consequent microaspiration. Several studies have found that tracheal tube cuffs composed of polyurethane or silicone prevent leakage of dye around the cuff, in comparison to conventional cuffs composed of polyvinylchloride, both in vitro and in vivo (Fig. 2). A small randomized trial in patients undergoing cardiac surgery found that tracheal intubation with a polyurethane-cuffed tube was associated with a reduced incidence of early postoperative pneumonia, compared to intubation with a traditional polyvinyl-chloride cuffed tube (23% vs 42%). Preliminary results from a study comparing VAP rates before and after introduction of a polyurethane-cuffed tube found that VAP rates were reduced from 5.5/1,000 to 2.8/1,000 ventilator days. Another randomized trial compared a tube that features both a polyurethane cuff and a subglottic suctioning port to a conventional tracheal tube in medical-surgical ICU patients and found a significant reduction in VAP among patients who used the specialized tube (22% vs 8%). However, it is
unclear if the benefit seen was related to the tube cuff, subglottic suctioning, or a joint effect of both ETT modifications. Neither of the above randomized trials detected a difference in duration of mechanical ventilation, ICU stay, or mortality between the groups. Cost-effectiveness data for these devices have not been reported. Thus, further evidence is needed before polyurethane-cuffed ETTs can be recommended as a widespread VAP prevention measure.

Two commercially available ETTs with polyurethane cuffs are available: Microcuff (Kimberley Clark, San Antonio, Texas) and Sealguard (Mallinckrodt, Covidien-Nellcor, Boulder, Colorado). There are no studies directly comparing these 2 tubes, and insufficient evidence upon which to base conclusions as to their relative efficacy.

No safety issues have been raised regarding polyurethane-cuffed ETTs, and there are no known theoretical concerns as to these tubes posing an added safety risk. However, safety data on the use of polyurethane-cuffed tubes are limited.

Antibacterial-Coated Endotracheal Tubes

In an effort to limit bacterial colonization and biofilm formation on the lumen of the ETT, investigators have studied tubes coated or impregnated with silver, silver sulfadiazine, and silver sulfadiazine plus chlorhexidine. Because of concerns about hypersensitivity reactions to chlorhexidine-impregnated devices, this agent has fallen out of favor as a tube coating. Silver sulfadiazine coating has been shown to prevent bacterial colonization of the ETT lumen in the experimental setting and in short-term intubation of patients; however, there are no data available on the efficacy of this intervention in preventing VAP.

Silver-coating of the ETT lumen is the best-studied of the antibacterial interventions. Pre-clinical and small clinical trials have documented a reduction in bacterial colonization of tubes internally coated with silver. Subsequently, a large, multicenter trial randomized 2,003 patients to tracheal intubation with either a conventional ETT or a tube coated with silver. The incidence of VAP was lower in the group of patients intubated for \( \geq 24 \) hours who used the silver-coated ETT (4.8% vs 7.5%, \( P = .03 \)). The difference was smaller when all intubated patients were considered (3.8% vs 5.8%, \( P = .04 \)). More importantly, and as might be expected given the relatively low incidence of VAP in that study, there was no effect of silver-coated ETT on other meaningful clinical outcomes, such as duration of mechanical ventilation, or ICU stay, or hospital stay. Furthermore, there was a worrisome trend toward increased mortality in patients randomized to the silver-coated ETT (30.9% vs 27.3%, \( P = .08 \)). The mechanism for a paradoxical effect on mortality of the silver-coated ETT was not addressed in the paper. Given these results and the lack of cost-effectiveness data on the use of this very expensive device, the silver-coated ETT cannot be recommended as a standard VAP-preventive intervention, and further investigation is warranted.

Other Miscellaneous Tubes and Devices

Other interventions designed to prevent or reduce VAP include modification of the ETT cuff shape and inflation characteristics, and devices designed to reduce mucus buildup on the lumen of the ETT (mucus slurpers and shavers). Similar to using polyurethane or silicone to manufacture the ETT cuff, changing the shape and inflation characteristics of the cuff is designed to eliminate folds in the in vivo inflated cuff that otherwise allow microaspiration. Although several ETTs with various cuff modifications are commercially available, there are insufficient clinical data to allow conclusions about their ability to prevent VAP. The Mucus Slurper is an ETT with suction ports arranged radially around the tip of the tube, and is designed to prevent the entry and buildup of tracheal secretions in the ETT lumen. Preclinical studies suggest that the Mucus Slurper is effective at reducing mucus buildup inside the ETT, although it had no effect on bacterial colonization of the trachea. There are no clinical reports on the use of this device. The Mucus Shaver, which shares developers with the Mucus Slurper, is an inflatable silicone-rubber “razor” that is introduced into the lumen of the ETT, thus allowing cleaning or “shaving” of material built up within the lumen. Laboratory studies suggest that the Mucus Shaver can reduce mucus buildup within the ETT, but the safety and efficacy of this device has not been reported in human subjects, and neither are there data documenting any effect on VAP development.

The LoTrach ETT (Intavent Orthofix, Berkshire, United Kingdom) is commercially available in Europe, and, sim-
ilar to the Sealguard Evac ETT, incorporates a low-vol-
ume, low-pressure cuff designed to inflate uniformly, com-
bined with a suction port for subglottic suctioning. Although this dual approach appears to be effective at
preventing short-term microaspiration, there are no published data on this device’s effects on the incidence of VAP.

Cost Concerns With Modified Endotracheal Tubes

In terms of estimated acquisition costs for hospitals, the
conventional, polyvinyl chloride-cuffed ETT costs approxi-
imately one dollar per tube, the polyurethane-cuffed ETT
costs between 3 and 4 dollars per tube, the polyurethane-
cuffed subglottic-suctioning ETT costs over $30 per tube,
and the silver-coated ETT costs over $100 per tube. The incremental costs of the modified tubes may be well justi-
fied, depending on their relative efficacy in reducing VAP.
However, the considerable increase in acquisition costs
compared to that of conventional tubes prohibits their rou-
tine, unselected use in the absence of reliable cost-effect-
iveness data. To date, these data have not been reported
for any of these devices, and modeling efforts to justify the high acquisition costs of these tubes have been severely flawed, as discussed below.

Shorr et al modeled the cost-effectiveness of using the
original subglottic-suctioning ETT (Hi-Lo Evac, Mallinck-
rodt, Covidien-Nellcor, Boulder, Colorado) with continu-
ous suctioning versus conventional ETTs, based on an
estimated VAP relative risk reduction of 30%, an increased
equipment cost of $14 per tube, and approximately $5,300
cost per case of VAP. They found a cost savings of
approximately $5,000 per case of VAP prevented. How-
ever, their VAP cost data were based on a predicted in-
creased ICU stay attributable to VAP of 5 days. In ad-
dition, this economic evaluation did not account for the
potential airway complications associated with the use of
the subglottic-suctioning ETT. The randomized trials of
subglottic suctioning found no effect of this intervention
on ICU stay, as confirmed by meta-analysis of intention-to-
treat data. Thus, the cost savings from subglottic suc-
tioning may be limited to the cost generated by the diag-
nosis and treatment of VAP, which Shorr et al estimated at
approximately $800. This may be less than the cost of
widespread use of the Hi-Lo Evac, particularly as VAP
rates are reduced by other interventions, if the device is
less effective than estimated, or if there are any compli-
cations associated with its use (see previous safety discus-
sion). These concerns are even greater given that the man-
ufacturer plans to replace the Hi-Lo Evac with the consid-
erably more expensive polyurethane-cuffed Seal-
guard Evac.

Likewise, Shorr et al modeled the cost effectiveness of
the silver-coated ETT (Agento IC, CR Bard, Murray Hill,
New Jersey) in preventing VAP, using an assumed VAP
relative risk reduction of 24%, a marginal cost of approxi-
mately $16,000 per VAP event, and an acquisition cost of
$90 per tube for the Agento IC. They predicted a savings
of $12,840 per case of VAP prevented, which persisted in
multivariate sensitivity analysis (95% CI $9,630–$16,356).
However, similar to the previous analysis of the cost-eff-
fectiveness of the subglottic-suctioning ETT, the cost per
VAP event was based on effects on multiple patient out-
comes, including reduced duration of ventilation and hos-
pital stay, none of which were affected by use of the
silver-coated ETT in the previously discussed randomized
controlled trial. Given the current extremely high acqui-
sion cost of the silver-coated ETT, it is unlikely that this
device would be cost saving if it has not been shown to be
effective in improving patient outcomes related to VAP.
At Harborview Medical Center in Seattle, Washington,
where over 1,000 emergency intubations are performed
per year, widespread and unselected use of the silver coated
ETTs would add over $100,000/year to the budget for
respiratory therapy equipment, an amount that is prohibi-
tive, barring more conclusive cost-effectiveness data.

Summary

VAP is a pervasive and expensive nosocomial infection
that is largely related to instrumentation of the airway with
an endotracheal tube, followed by microaspiration of con-
taminated secretions. VAP prevention will probably be
most effective via a multifaceted approach, which includes
meticulous attention to basic infection-control methods dur-
ing patient care, proper patient positioning, oral hygiene,
and removal of the ETT as soon as indicated. Modification
of the ETT to reduce microaspiration and/or biofilm for-
tation may also play an important role in VAP preven-
tion. However, despite numerous studies of various such
interventions, there is insufficient evidence upon which to
base strong recommendations, and important safety con-
cerns remain regarding the use of the subglottic-suctioning
ETT and the silver-coated ETT. Most importantly, cost-
effectiveness data are lacking for these device-associated
VAP-preventive measures. It is critical that future studies
of ETTs designed to prevent VAP be adequately powered
to demonstrate efficacy on important patient outcomes and
safety, in addition to cost-effectiveness. These studies need
to be conducted in a setting reproducing the clinical situ-
atation of emergency tracheal intubation, and in the context
of a bundled approach to the prevention of VAP.

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