

Continuous Subglottic Suctioning for the Prevention of Ventilator-Associated Pneumonia*

Potential Economic Implications

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Study objective: To determine the cost-effectiveness of continuous subglottic suctioning (CSS) as a strategy to decrease the incidence of ventilator-associated pneumonia (VAP).

Design: Decision-model analysis of the cost and efficacy of endotracheal tubes that allow CSS at preventing VAP. The primary outcome was cases of VAP averted. Model estimates were based on data from published prospective trials of CSS and other prospective studies of the incidence of VAP.

Setting and patients: Hypothetical cohort of 100 patients requiring nonelective endotracheal intubation and management in an ICU.

Interventions: In the model, patients were managed with either traditional endotracheal tubes (ETs) or ETs capable of CSS.

Measurements and main results: The marginal cost-effectiveness of CSS was calculated as the savings resulting from cases of VAP averted minus the additional costs of CSS-ETs, and expressed as cost (or savings) per episode of VAP prevented. Sensitivity analysis of the impact of the major clinical inputs on the cost-effectiveness was performed. The base case assumed that the incidence of VAP in patients requiring > 72 h of mechanical ventilation (MV) was 25%, that CSS-ETs had no impact on patients requiring MV for < 72 h, and that CSS-ETs resulted in a relative risk reduction of VAP of 30%. Despite the higher costs of ETs capable of CSS, this tactic yielded a net savings of \$4,992 per case of VAP prevented. For sensitivity analysis, model inputs were adjusted by 50% individually and then simultaneously. This demonstrated the model to be only moderately sensitive to the calculated cost of VAP. With the relative risk reduction at 50% of the base-case estimate, CSS resulted in \$1,924 saved per case of VAP prevented. When all variables were skewed against CSS, total outlays were trivial (approximately \$14 per patient in the cohort).

Conclusions: CSS represents a strategy for the prevention of VAP that may result in savings. Further studies are warranted to confirm the efficacy of CSS.

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Key words: cost; cost-effectiveness; endotracheal tube; pneumonia; prevention; subglottic; suctioning; ventilator

Abbreviations: CSS = continuous subglottic suctioning; ET = endotracheal tube; MV = mechanical ventilation; VAP = ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) continues to be a significant cause of morbidity and mortality in critically ill patients. VAP is the leading cause

of mortality related to nosocomial infection, with a crude mortality rate ranging from 50 to 70%.¹⁻⁶ The attributable mortality from VAP is less but may be as high as 25%.²⁻⁴ VAP also increases the duration of both intensive care and hospitalization and therefore results in increased medical costs. The extra stay in the ICU for patients who develop VAP may be as high as 9 days.⁶ A number of preventive strategies directed at limiting the incidence and impact of VAP exist: changing ventilator circuitry less frequently, selective digestive decontamination with antibiotics, and enforcing adequate hand washing in the ICU.^{1,6} Another option for the prevention of VAP is the use of endotracheal tubes (ETs) that allow for the continuous suctioning of subglottic secretions. ETs di-

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rectly contribute to the development of VAP by impairing the cough reflex and by promoting nosocomial sinusitis.⁷ Furthermore, secretions that pool above the cuff of an ET often contain Gram-negative bacilli that have colonized the oropharynx.^{8–10} Aspiration of these secretions can result in VAP.¹¹ ETs modified to permit continuous subglottic suctioning (CSS) have been shown to decrease the incidence of VAP. Such ETs, however, are significantly more expensive than standard ETs. Additionally, the studies demonstrating the efficacy of CSS have focused mainly on patients at high risk for VAP.¹¹ Since predicting whether a patient is at high risk for VAP may be difficult, CSS has not been widely adopted and is only recommended for use as part of an organized approach to VAP prevention.⁶ Since there have been few prospective trials of CSS, it is important to determine the potential financial implications of this strategy. Estimating the cost-effectiveness of CSS will facilitate the design of further prospective trials and will allow comparisons between CSS and other interventions designed to decrease the incidence of VAP.

We hypothesized that despite their higher cost the use of ETs designed for CSS might be cost-effective relative to standard ETs. Given the significant financial expenses associated with VAP, if CSS were employed regularly for nonelective endotracheal intubations, it might result in cost savings, even if it only slightly reduced the incidence of VAP. To test this hypothesis, we developed a decision model to compare the costs of CSS and standard ETs relative to the costs associated with the development of VAP.

MATERIALS AND METHODS

We performed a cost-effectiveness analysis employing a decision-model approach. The recommendations of the Panel on Cost-Effectiveness in Health and Medicine for reference-cases analyses were followed.¹² We compared health and economic outcomes in terms of VAP prevention with CSS to the use of standard ETs. We calculated the marginal cost-effectiveness of CSS as the additional costs associated with CSS-ETs minus any cost savings resulting from the use of CSS-ETs divided by the cases of VAP prevented. This ratio is expressed as the cost (or savings) per case of VAP prevented. We did not discount costs, as the impact of the potential outcomes was immediate. The target population for this assessment included patients undergoing nonelective endotracheal intubation, irrespective of the estimated duration of MV. By “nonelective” endotracheal intubation, we mean those ETs whose placement is not coincident with a previously planned intervention or procedure, such as an operation, endoscopy, or radiology study. We compared two hypothetical cohorts of 100 patients each.

Model Structure

We modeled the significant outcomes via a simple decision tree (Fig 1). The only decision node represented the determination

whether to employ CSS-ETs or standard ETs. The single major health end point was the development of VAP and is represented as a chance node in the decision tree. We segregated patients into those requiring MV for > 72 h and those requiring < 72 h of ventilatory support. This was done because in the study by Valles et al,¹¹ patients were excluded from study enrollment if the anticipated duration of MV was < 72 h. The relevant measure of effectiveness therefore is the cases of VAP averted, while the significant economic end points include the extra costs associated with the procurement of CSS-ETs and the costs associated with VAP.

Data Sources

The model required the following five major inputs: the proportion of patients requiring MV for > 72 h, the incidence of VAP in the cohort, the relative risk reduction of CSS, the accrual costs associated with CSS-ETs and conventional ETs, and the cost of VAP (Table 1). The proportion of patients requiring MV for > 72 h was abstracted from the data collected for the APACHE (acute physiology and chronic health evaluation) III database.¹³ To determine the incidence of VAP in patients requiring MV for < 72 h or > 72 h, respectively, we performed a literature search of MEDLINE to identify all English-language randomized, controlled trials for the prevention of VAP, and prospective, cohort incidence studies of VAP. Key words used for the search included the following: incidence, nosocomial, pneumonia, prevalence, prevention, and ventilator. Key words were cross-referenced with each other as appropriate. Only literature published since 1994 was used, as earlier articles may no longer be applicable to present ICU practice. From these articles, we estimated the incidence of VAP as a function of the duration of MV.^{11,14–39} Rather than formally evaluate the quality of each of these studies, we relied on sensitivity analysis (see below) to gauge the importance of uncertainty regarding these inputs.

The relative risk reduction for CSS was derived primarily from the study of Valles et al.¹¹ This was a randomized controlled trial of CSS-ETs vs standard ETs for the prevention of VAP. The strengths of this study have been reviewed in detail elsewhere. Valles et al¹¹ reported a cumulative incidence of VAP in 18.4% of individuals managed with CSS, as compared to 32.5% in patients treated with conventional ETs. In other words, this approach resulted in a 43.4% relative risk reduction.

The cost for a CSS-ET was obtained from the manufacturer (Mallinckrodt; St. Louis, MO), while the cost for a conventional ET represents the actual cost to our institution for a standard ET. The costs of a case of VAP comprises the costs associated with the following: (1) diagnosis of this process, (2) its treatment, and (3) the degree to which it prolongs ICU care. We did not assume that VAP similarly prolonged non-ICU hospitalization. To determine these variables, we multiplied the component charges our institution bills to third-party payers by a cost-to-charge ratio of 0.6. This is considered by others to be a true surrogate for inpatient cost accounting.⁴⁰ We obtained charge data from the billing service of our hospital.

Model Inputs

Table 1 shows the variables used for the base-case scenario. We estimated the incidence of VAP in all patients requiring MV < 72 h to be 5.0%, as compared to 25.0% in patients needing > 72 h of MV. In the articles reviewed, the incidence of VAP ranged from 4.0% to 7.5% for patients receiving MV for < 72 h and from 25.0% to 40.8% in patients receiving MV for > 72 h. Also shown in Table 1 is the estimated relative risk reduction of CSS for our

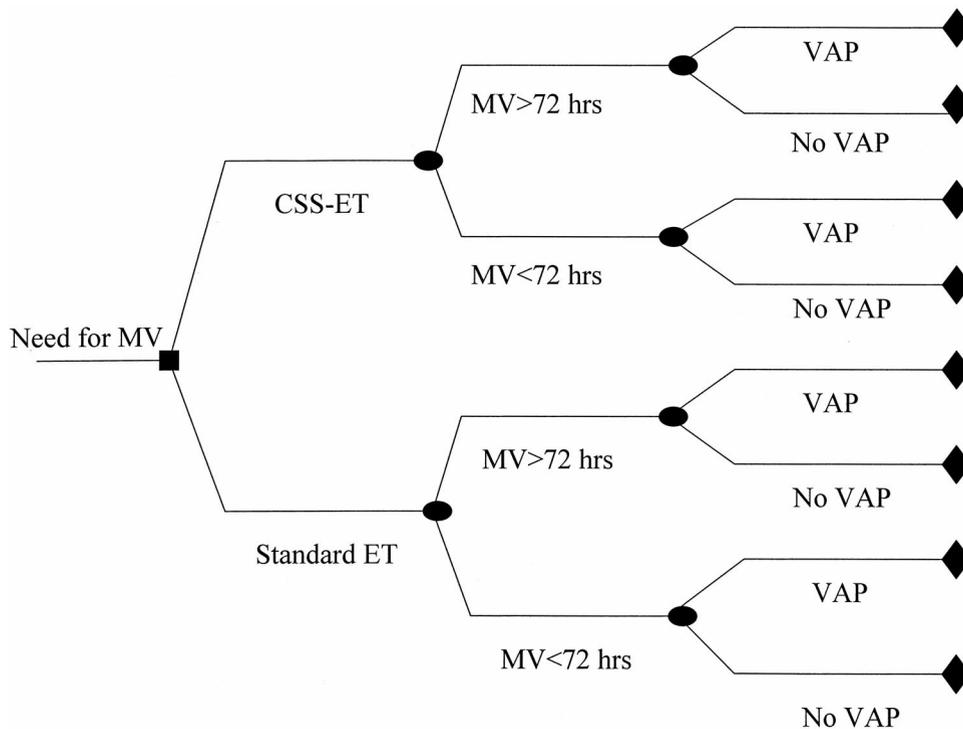


FIGURE 1. At left, the square node represents the decision whether to employ ETs capable of CSS. The circular nodes are “chance nodes” designating the probabilities regarding the duration of MV and the development of VAP. The diamond-shaped nodes at the completion of each path represent the costs and health effects associated with the complete sequence of events in that particular path.

hypothetical cohort. For the initial analysis, we assumed the CSS reduced the incidence of VAP by 30.0%. This is lower than the effect reported by Valles et al.¹¹ This assumption would tend to bias our analysis toward standard ETs. Moreover, we believed a lower estimate of efficacy was justified, since the lumens of CSS-ETs may become occluded and thus fail to function (M. Kollef, MD; personal communication; January 2000). The cost of a CSS-ET is at present \$15, while our institution pays approximately \$1 for a conventional ET.

The costs associated with a case of VAP are shown in Table 2. For the diagnosis of VAP, we assumed a patient would require a chest radiograph, blood and sputum cultures, and a CBC count. The costs for the diagnostic evaluation were \$234. We did not include costs for a more invasive approach such as bronchoscopy. For the treatment of VAP, we assumed the patient would receive a 14-day course of IV antibiotics. At our hospital, the most frequently used regimen is ceftazadime with gentamycin, which would result in a cost of \$556. We relied on the results by

Heyland et al² to estimate that patients who develop VAP spend approximately 5 days longer in the ICU than do patients requiring MV but who do not develop VAP. Most earlier studies of this issue have reported that patients with VAP require from 6 to 9 additional days of ICU case. The study by Heyland et al,² however, represents data recorded during a large multicenter prospective trial, and therefore is a more likely to represent an accurate assessment of the attributable ICU length of stay associated with VAP. Since the cost per day in the ICU is \$915, aggregate expenditures for the increased ICU stay are \$4,575. Hence, the total cost associated with a case of VAP is \$5,365. Since we did not include costs associated with the additional care required for a patient with VAP while in the ICU (eg, additional radiology and laboratory studies, extra respiratory-care treatments), we may have underestimated the true costs of VAP. For comparative purposes, Table 3 shows the estimates of others of the costs of VAP.⁴¹⁻⁴³

Table 1—Model Inputs*

Variables	Estimate	Ranges Tested	References
Patients requiring MV for > 72 h, %	50.0	25.0–75.0	13
Incidence of VAP in patients requiring > 72 h of MV, %	25.0	12.5–37.5	14–39
Incidence of VAP in patients requiring < 72 h of MV, %	5.0	2.5–7.5	14–39
RRR of CSS, %	30.0	15.0–45.0	11
Cost of VAP	\$5,365	\$8,048–\$2,683	NA
Cost of standard ET	\$1	NA	NA
Cost of CSS-ET	\$15	NA	NA

*RRR = relative risk reduction; NA = not applicable.

Table 2—Costs Associated With VAP

Components	Cost
Diagnostic evaluation	\$234
Treatment	\$556
Prolonged ICU stay	\$4,575
Total	\$5,365

Table 3—Prior Estimates of the Cost of VAP

Source	Year	Cost
Jarvis ⁴¹	1988	\$4,947
Boyce et al ⁴²	1990	\$5,800
Ben-Menachem et al ⁴³	1996	\$10,062

Sensitivity Analysis

We used sensitivity analysis to identify important model uncertainties and to assess the robustness of our conclusions.¹² Since the incidence of VAP may vary widely depending on the population studied, sensitivity analysis also affords a mechanism to assess the cost implications of CSS across a range of estimates for the risk of VAP. We varied base-case estimates by 50% individually in order to identify variables that substantially affected the results. We also adjusted all model inputs by 50% simultaneously to provide a multivariate assessment of best-case and worst-case scenarios.

RESULTS

Base Case

In the base-case scenario, there are 8.75 instances of VAP when CSS is employed, compared to 12.5 episodes of VAP with the use of standard ETs. Total costs are \$61,856 with CSS, as compared to \$80,575 with conventional ETs. VAP-related costs with CSS-ETs are \$18,719 less than the costs incurred with standard ETs. Each prevented case of VAP (marginal cost savings) is associated with \$4,992 net savings. On a per-patient basis, the use of CSS yields \$1,872 in savings for each individual in the cohort. This

significant per-patient savings arises despite the fact that CSS-ETs are 15 times more expensive than conventional ETs.

Sensitivity Analysis

When each input is adjusted alone (*eg*, one at a time), the total cost savings of CSS-ETs was equally sensitive to each variable, except the incidence of VAP in patients requiring < 72 h of MV. Analyzing the marginal cost savings (net savings divided by cases of VAP prevented) revealed the model to be most sensitive to the estimated cost of VAP (Fig 2). When the cost of VAP was halved, the marginal cost savings of CSS decreased from \$4,992 to \$1,924. More importantly, however, a 50% decrease in the cost of VAP does not alter the primary result with respect to CSS-ETs yielding savings. We also performed threshold analysis to determine at what point CSS-ETs no longer provide savings. Only when the relative risk reduction of CSS-ETs falls below 2.1% or when the cost of VAP is < \$373 does the use of CSS-ETs require additional net expenditures.

Table 4 shows a two-way sensitivity analysis of the marginal cost savings associated with CSS-ETs, varied by both the relative risk reduction of CSS-ETs

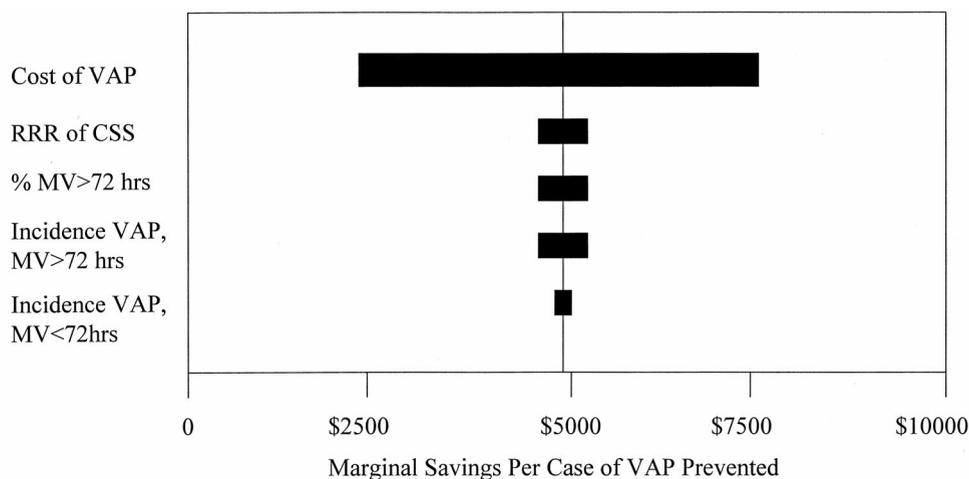


FIGURE 2. The solid vertical line designates the marginal cost-effectiveness of CSS for the base-case scenario. The horizontal bars demonstrate the range in marginal cost-effectiveness resulting when a particular input is varied between its upper and lower limit while other variables are held constant. See Table 1 for abbreviations.

Table 4—Marginal Cost Savings of CSS Based on Estimated Relative Risk Reduction and Cost of VAP

Cost of VAP	Relative Risk Reduction of CSS, %				
	15	22.5	30	37.5	45
\$2,683	\$1,936	\$2,185	\$2,310	\$2,376	\$2,434
\$4,024	\$3,277	\$3,526	\$3,650	\$3,717	\$3,775
\$5,365	\$4,618	\$4,867	\$4,992	\$5,058	\$5,116
\$6,706	\$5,959	\$6,208	\$6,333	\$6,399	\$6,457
\$8,048	\$7,301	\$7,550	\$7,675	\$7,741	\$7,799

and the costs of VAP. Changing these estimates affected the marginal cost savings moderately, but did not alter the observation that CSS results in total savings. For example, when CSS-ETs were assumed to be minimally effective and the cost of VAP was low, the marginal cost savings was \$1,936, or 38.8% of the marginal cost savings noted in the base case. In a scenario more favorable to CSS-ETs (45% relative risk reduction for VAP and cost per case of VAP set at \$8,048) the marginal cost savings increased to \$7799. To determine if CSS-ETs ever resulted in additional costs rather than savings, we manipulated each input variable simultaneously by 50%. With all inputs skewed to make CSS-ETs as unattractive as possible, the use of CSS-ETs prevents 0.47 cases of VAP and results in a minor total cost outlay of \$143, or \$14.30 per patient in the cohort.

DISCUSSION

This decision model demonstrates that CSS-ETs are not only highly cost-effective but that they may also be associated with significant savings if regularly employed for all nonelective endotracheal intubations. Although CSS-ETs cost more than traditional ETs, this difference is outweighed by the high costs associated with VAP.

To date, the use of CSS-ETs has been limited because few studies exist demonstrating their efficacy.^{11,39,44} However, for clinicians, predicting whether a specific patient in a particular situation might benefit for CSS is difficult. Therefore, physicians may be reluctant to employ CSS-ET, particularly in light of their cost relative to standard ETs. This decision analysis represents an effort to grapple with this dilemma. We modeled the use of CSS-ETs as would likely occur in clinical practice if their use were to become more widely adopted. Moreover, our decision analysis acknowledges the possibility that for some proportion of patients undergoing nonelective endotracheal intubation, CSS-ET would confer no protection from VAP. Such patients might be extubated relatively quickly and would therefore

be unlikely to develop VAP. An additional strength of our model is that it incorporates the possibility that VAP may, nonetheless, occur in individuals requiring < 72 h of MV.

The model was also biased with assumptions favoring the use of standard ETs. For example, in order to be conservative, we employed a relative risk reduction for VAP of 30%, while in their original study Valles et al¹¹ noted that CSS-ET reduced the incidence of VAP by > 42%. Kollef et al³⁹ noted that CSS reduced the risk of VAP in patients undergoing cardiac surgery by 41%. We chose the lower base-case estimate to account for potential tube failure secondary to occlusion of the suction port of the ET. Similarly, our cost estimate of VAP is likely to be lower than the true costs of VAP, and this would favor standard ETs. Specifically, we excluded charges associated with invasive testing for VAP, used a lower range estimate of the degree to which VAP prolongs ICU stay, and assumed that VAP did not prolong the duration of non-ICU hospitalization. As shown in Table 3, our estimate of the cost of a case of VAP is approximately 50% of the value determined in another, more recent study.⁴³

Sensitivity testing demonstrated that our conclusions about savings associated with CSS-ETs are robust over a wide range of values for each of the uncertainties of the model. The most important variable with regard to our conclusions was the cost of VAP. Varying the cost of VAP by 50%, though, did not alter the principal finding. In accordance with the recommendations of the Panel on Cost-Effectiveness in Health and Medicine, we also performed multivariate sensitivity analysis.¹² Readers should note that traditionally, sensitivity analyses vary inputs by 25%.⁴⁵ Since significant uncertainty exists with respect to the inputs of this model (*eg*, the relative risk reduction for CSS-ETs, and the cost of VAP) we altered assumptions by 50% rather than 25%. When every variable was simultaneously adjusted by 50% to favor regular ETs, CSS-ETs resulted in a trivial increase in total costs.

In comparison to other prophylactic interventions in the ICU, CSS provides similar, if not potentially greater, savings. Veenstra et al⁴⁶ estimated via decision analysis that the use of antiseptic-impregnated central venous catheters, although more costly than standard central venous catheters, saved between \$68 and \$39 per blood stream infection prevented. For the prevention of atrial fibrillation complicating cardiac surgery, Reddy et al⁴⁷ concluded that the regular use of amiodarone perioperatively yielded \$1,676 in savings per case of atrial fibrillation avoided. Schumock and colleagues⁴⁸ determined that sucralfate was more cost-effective for stress ulcer prophylaxis than histamine H₂-receptor antag-

onists, and would result in a net savings of \$7,373 per case of acute GI bleeding averted. CSS also compares favorably in terms of cost-effectiveness with other interventions routinely undertaken in the care of the patient requiring MV. In a prospective trial including 521 patients, Kollef et al²⁴ demonstrated that changing in-line suction catheters as needed rather than every 24 h saved a total of \$10,179. In a similar study of 310 patients, Kollef and colleagues²⁶ showed that employing an extended-use hygroscopic condenser for humidification as opposed to a heated-water humidification system saved on average \$10 per patient. With respect to specific efforts designed to decrease the incidence of VAP, Garcia et al²⁵ demonstrated that selective digestive decontamination led to lower total costs. Based on the data provided in their study, we calculated the cost-effectiveness of this approach as \$11,400 in savings per case of VAP avoided.²⁵ Of course, however, some interventions such as hand washing and elevation of the head of the bed are without cost.

Our study has several limitations. First, we relied on only one study to approximate the relative risk reduction conferred by CSS. This study has several limitations and was unblinded.^{11,49} In other words, the data regarding the extent of the benefit of CSS are limited. The only other study examining subglottic suctioning in patients likely to require prolonged MV showed this approach to be effective with the rate of VAP decreasing from 29.1 to 12.9%.⁴⁴ This trial, however, employed intermittent rather than continuous subglottic suctioning, and simultaneously randomized patients to different means of stress ulcer prophylaxis.⁴⁴ In a more focused study limited to a cohort of patients at a lower risk for VAP, namely those undergoing cardiac surgery, Kollef et al³⁹ reported a 41% decrease in VAP with the use of CSS-ETs. This difference was not statistically significant, however, and likely reflects the limited power of the study given the low incidence of VAP in the cohort. Second, our estimates of the probability of VAP based on the duration of MV are from literature describing both specific cohorts of patients (*eg*, trauma patients) and mixed ICU populations. Choosing a precise incidence rate therefore is difficult, and the value of any model rests on the quality of the inputs. Our different sensitivity analyses address this concern directly by specifically altering the estimated incidence of VAP across a wide range of inputs. Third, our model assumes that all types of VAP are similar with respect to their financial implications. Early-onset VAP, which CSS has been shown to decrease, may not prolong ICU stay to the same degree that late-onset VAP does. Early-onset VAP, for example, is often caused by less virulent organisms. Our reliance on a relatively low estimate

of the cost of VAP was, in part, designed to address this issue. Similarly, that we did not rely on an invasive approach for the diagnosis of VAP biased our model in favor of regular ETs. An invasive diagnostic strategy would have increased the total costs associated with the diagnosis of VAP. Fourth, we artificially segregated patients based on whether the estimated duration of MV was > 72 h. In practice, it is difficult to estimate the duration of MV. We used this assumption, since the positive trials dealing with CSS have attempted to focus on patients likely to require MV for >72 h. That the model was not sensitive to the proportion of subjects needing MV for > 72 h underscores that this dichotomy does not significantly impact our findings. Finally, we did not assume a purely societal perspective for the decision model. We focused on cost savings (to both patient and institution) because few data exist to allow one to determine to what extent, if any, preventive strategies for VAP increase more general measures of health outcomes. Lack of a societal perspective, in turn, limits the ability to compare our results with other health-care interventions measured in terms of quality-adjusted life years.

In conclusion, an economic analysis of the impact of CSS demonstrates that the regular utilization of CSS-ETs for nonelective endotracheal intubations may produce significant savings, irrespective of the increased costs of CSS-ETs. This observation holds across a wide range of assumptions regarding the incidence of VAP, the risk reduction associated with CSS-ETs, and the costs of VAP. Because of these findings, further studies are warranted to corroborate the efficacy of CSS-ETs. If confirmed, critical-care physicians should consider employing CSS-ETs more frequently.

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