Closed tracheal suction systems for prevention of ventilator-associated pneumonia

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We have assessed the evidence that closed tracheal suction systems (TSS) prevent ventilator-associated pneumonia (VAP), using a meta-analysis of randomized controlled trials (RCTs). We searched PubMed and Cochrane databases to identify RCTs that compared closed with open TSS for the management of mechanically ventilated (MV) patients. Nine RCTs were included in the meta-analysis. There was no difference in the incidence of VAP between patients managed with closed and open TSS [odds ratio (OR) = 0.96, 95% confidence intervals (CI) 0.72–1.28]. There was no heterogeneity among the eligible trials (I² = 0, 95% CI 0–0.65). The compared groups did not differ with respect to mortality (OR = 1.04, 95% CI 0.78–1.39) or intensive care unit (ICU) length of stay [two RCTs: 12.3 (SD 1.1) vs 11.5 (1.4) days and 15.6 (13.4) vs 19.9 (16.7) days]. Suctioning with closed systems was associated with longer MV duration (weighted mean differences: 0.65 days, 95% CI 0.28–1.03) and higher colonization of the respiratory tract (OR = 2.88, 95% CI 1.50–5.52) than open TSS. The available evidence suggests that closed as opposed to open TSS usage did not provide any benefit on VAP incidence, mortality, or ICU stay of MV patients.

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Between 8% and 28% of patients receiving mechanical ventilation (MV) in the intensive care unit (ICU) can contract ventilator-associated pneumonia (VAP),⁶ which increases mortality and morbidity.¹⁷ ³⁶ ³⁷ Several techniques for the management of MV patients have been employed to reduce the risk for the development of VAP.

Among the most common supportive measures for MV patients is the endotracheal suctioning, performed with either closed multi-use catheter tracheal suction systems (TSS) or open single-use catheter TSS. Although preliminary studies reported that closed TSS reduced the risk of developing a respiratory infection, the comparative effectiveness over open TSS for prevention of VAP remains controversial. Branson³ recently stated that the conventional wisdom that fewer breaks of the circuit results in a lower risk of contamination clearly supports the employment of closed TSS. Subsequently, Craven¹⁰ stated that the use of closed TSS as a preventive measure is optional, even though three randomized controlled trials (RCTs) showed no effect on VAP.

It seems that although the use of closed TSS is considered for the prevention of VAP, scepticism exists about their usefulness. Thus, to assess the comparative effectiveness of closed over open TSS for the prevention of VAP in critically ill patients, we conducted a meta-analysis of the published RCTs on the topic.

Methods

We used guidelines from the Quality of Reporting of Meta-Analyses conference.²⁶ We searched systematically the PubMed (up to September 2007) and the Cochrane Central Register of Controlled Trials by using the following key terms: ‘ventilator-associated pneumonia’ or ‘ventilator associated pneumonia’ or ‘nosocomial pneumonia’ and ‘suction’ or ‘suctioning’. We additionally reviewed the references of the selected articles. We did not seek for abstracts presented in scientific conferences.

Two reviewers (I.I.S. and K.Z.V.) independently performed the literature search. A RCT was considered eligible, if (a) it examined the role of closed TSS in comparison with open TSS for the management of patients receiving MV and (b) it reported on the incidence of VAP. Only RCTs conducted in adult patients and written in English, French, or German were included in the analysis.
In contrast, we omitted trials focusing on special issues of endotracheal suctioning (e.g., the frequency of change of closed TSS catheter), trials comparing different types of closed TSS, and trials evaluating only the effects on gas exchange and haemodynamics.

Two reviewers (I.I.S and K.Z.V.) independently extracted the data from all eligible articles: year of publication, study design, study population, severity of illness on ICU admission, brand of closed TSS used, co-interventions, and criteria used in each of the selected RCTs for the definition of VAP. Incidence of VAP, mortality, length of ICU stay, duration of MV, colonization of the respiratory tract, and cost associated with TSS usage were recorded. Any disagreement between the two reviewers was resolved by the consensus of all authors. We also independently rated the methodological quality of each RCT by using a modified Jadad score.27 We assessed the following components: randomization, generation of random numbers, details of double-blinding procedure, information on withdrawals, and concealment of allocation. One point was awarded for the specification of each criterion; the maximum score for a study is 5. Finally, we collected information on the source of funding of the eligible RCTs, because it has been found that industry-funded studies are more likely to have positive results.

**Analysed outcomes**

The primary outcome for this meta-analysis was the incidence of VAP (until patient’s death or discharge from the ICU) for all patients included in the selected RCTs. All-cause mortality, length of ICU stay, duration of MV, colonization of the respiratory tract, and cost associated with the usage of these systems were regarded as secondary outcomes.

**Definitions**

**Ventilator-associated pneumonia**

Pneumonia was defined by clinical, laboratory, and imaging findings attributed by the authors of the trials to this infection. To be considered as ventilator-associated, the above findings of pneumonia should be present in patients receiving MV for at least 48 h.

**Colonization of the respiratory tract**

Colonization was defined by the isolation of one or more micro-organisms from sputum or bronchial secretions of the patients without accompanying evidence of infection of the respiratory tract.

**Data analysis and statistical methods**

Statistical analyses were performed using the ‘S-PLUS 6.1’ software. The heterogeneity between RCTs was assessed by using both a $\chi^2$ test (a $P$-value lower than 0.10 was defined to note statistical significance) and the $I^2$ statistic. Publication bias was assessed by the funnel plot method using Egger’s test.15 Continuous outcomes were analysed using weighted mean differences (WMDs) and 95% confidence intervals (CI). Pooled odds ratios (OR) and 95% CI for the outcomes of this meta-analysis were calculated by using the DerSimonian–Laird random effects model.

**Results**

**Selected RCTs**

The electronic database search yielded 23 potentially relevant RCTs; three more RCTs that were not captured in the initial search were found through the review of the references of the relevant articles. From these, 17 reports were retrieved for further evaluation. Eight out of the 17 RCTs were omitted for the reasons detailed in Figure 1. Finally, nine RCTs included in the meta-analysis.

**Characteristics of the selected studies**

For the nine RCTs included in the meta-analysis (Table 1), the quality score for five trials was 1 and for the other four trials was 2. One of the selected RCTs enrolled orthotopic liver transplant patients for chronic liver failure, whereas the other RCTs included immunocompetent patients. The compared groups of patients (i.e., those managed with closed and those managed with open TSS) were similar at the time of randomization with respect to demographic characteristics and severity of illness (Table 1) in each of those included in the meta-analysis RCTs. In the majority of the eligible RCTs, diagnosis of VAP was based on clinical, laboratory, and imaging findings, whereas in three RCTs qualitative cultures were also required for the microbiological confirmation of the VAP.

In seven of the selected RCTs, the catheter of the closed TSS was replaced every 24 h, whereas in the remaining two RCTs, the catheter was changed only when it was grossly contaminated with secretions or its integrity was disrupted. Frequency of endotracheal suctioning was at nurse’s discretion in the seven RCTs that provided specific data on this issue. Information on interventions other than endotracheal suctioning for the management of MV patients was mentioned in eight of the selected RCTs (Table 1).

Six trials did not provide any details of the source of funding, one trial reported that no funding was granted, another RCT was supported by a grant from the University, and the remaining RCT was, in part, industry-funded.
Incidence of VAP
All the RCTs included in the meta-analysis reported outcomes on the incidence of VAP (Table 2).\(^1\)\(^8\)\(^{12}\)\(^{20}\)\(^{24}\)\(^{25}\)\(^{29}\)\(^{38}\)\(^{42}\) There was no heterogeneity among the identified comparisons (\(P=0.49, I^2=0, \text{95\% CI 0–0.65}\)). Publication bias was not detected (Egger’s test \(P=0.08\)). There was no difference in the incidence of VAP between patients suctioned with closed or open TSS (OR=0.96, 95% CI 0.72–1.28). The OR for VAP incidence in the individual RCTs, and the pooled OR, are in Figure 2.

Subgroup analyses
First, a subgroup analysis was conducted after the exclusion of the RCT that enrolled immunocompromised patients who received ICU care after liver transplantation.\(^1\) Performance of closed TSS in immunocompetent MV patients was not associated with lower VAP incidence compared with open TSS (OR=0.95, 95% CI 0.70–1.29, data from eight RCTs\(^8\)\(^{12}\)\(^{20}\)\(^{24}\)\(^{25}\)\(^{29}\)\(^{38}\)\(^{42}\)). Likewise, there was no difference between the compared TSS regarding VAP incidence in the both subset analyses of studies published after (OR=0.99, 95% CI 0.64–1.51, data from five RCTs\(^{24}\)\(^{25}\)\(^{29}\)\(^{38}\)\(^{42}\)) and before (OR=0.73, 95% CI 0.38–1.40, data from four RCTs\(^1\)\(^{8}\)\(^{12}\)\(^{20}\)) the year 2003.

Secondary outcomes
Mortality
Five of the RCTs included in the meta-analysis reported on all-cause mortality.\(^8\)\(^{12}\)\(^{24}\)\(^{25}\)\(^{38}\) Heterogeneity among the comparisons (\(P=0.94, I^2=0, \text{95\% CI 0–0.79}\)) and publication bias (Egger’s test \(P=0.47\)) were not found. Mortality was not different between patients managed with closed or open TSS (OR=1.04, 95% CI 0.78–1.39).
<table>
<thead>
<tr>
<th>First author [ref.]</th>
<th>Country/ year of publication</th>
<th>Study design/ study quality score *</th>
<th>Type of ICU/study population</th>
<th>Number of patients included</th>
<th>Severity of illness on ICU admission [mean (sd)]</th>
<th>Brand of closed tracheal suction system used/ frequency of catheter’s change</th>
<th>Co-interventions/frequency of suctioning [times per day, mean (sd)]</th>
<th>Definition of VAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lorente [24]</td>
<td>Spain/2006</td>
<td>RCT/2</td>
<td>Medical-surgical/patients requiring MV</td>
<td>457 (236 vs 221)</td>
<td>APACHE II: 13.8 (8.8) vs 13.7 (8.7)</td>
<td>Hi-Care (Mallinckrodt, Mirandola, Italy)/only when it presented mechanical failure or soiling or when the patient needed re-intubation</td>
<td>No routine change of ventilator circuits, HME (changed every 48 h), SRBP, CEN, periodic verification of residual gastric volume, ranitidine for stress ulcer prophylaxis, oral washing with chlorhexidine, no CASST nurse’s discretion [8.1 (2.7) vs 7.9 (2.6)]</td>
<td>All the following: new or progressive infiltrate on chest X-ray, purulent sputum, T &gt;38°C (or &lt;35.5°C), WBC &gt;12 000 (or &lt;3000) cells mm⁻³, and culture of respiratory secretions (TA &gt;10⁶ CFU ml⁻¹, BAL &gt;10⁴ CFU ml⁻¹), or PSB &gt;10⁷ CFU ml⁻¹) or blood culture coinciding with the respiratory secretion culture</td>
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<tr>
<td>Lorente [25]</td>
<td>Spain/2005</td>
<td>RCT/2</td>
<td>Medical-surgical/patients requiring MV &gt;24 h</td>
<td>443 (210 vs 233)</td>
<td>APACHE II: 15.5 (6.2) vs 15.8 (6.3)</td>
<td>Hi-Care (Mallinckrodt, Mirandola, Italy)/every 24 h</td>
<td>No routine change of ventilator circuits, SRBP, CEN, periodic verification of residual gastric volume, ranitidine for stress ulcer prophylaxis, no SDD, no CASST nurse’s discretion [8.1 (3.5) vs 8.3 (3.7)]</td>
<td>All the following: new or progressive infiltrate on chest X-ray, purulent sputum, T &gt;38°C (or &lt;35.5°C), WBC &gt;12 000 (or &lt;3000) cells mm⁻³, and culture of respiratory secretions (TA &gt;10⁶ CFU ml⁻¹, BAL &gt;10⁴ CFU ml⁻¹, PSB &gt;10⁷ CFU ml⁻¹) or blood culture coinciding with the respiratory secretion culture</td>
</tr>
<tr>
<td>Topeli [38]</td>
<td>Turkey/2004</td>
<td>RCT/1</td>
<td>Medical/patients requiring MV &gt;48 h without malignancy</td>
<td>78 (41 vs 37)</td>
<td>APACHE II: 25.6 (1.1) vs 23.8 (1.3)</td>
<td>Steri-Cath (Sims Portex, USA)/ when the catheter was grossly contaminated with secretions or his integrity was disrupted</td>
<td>HMEs/NA</td>
<td>New or progressive infiltrate on chest X-ray and two of the following: purulent TA, T &gt;38°C (or &lt;35.5°C), and WBC &gt;10 000 (or &lt;3000) cells mm⁻³</td>
</tr>
<tr>
<td>Rabitsch [29]</td>
<td>Austria/2004</td>
<td>RCT/2</td>
<td>Medical/patients (&gt;18 yr) requiring MV &gt;72 h</td>
<td>24 (12 vs 12)</td>
<td>APACHE II: did not differ between the compared groups</td>
<td>TrachCare (Tyco Healthcare, Neustadt/ Donau, Germany)/ every 24 h</td>
<td>Oral care without antiseptics, PPIs for stress ulcer prophylaxis/at nurse’s discretion (at least every 4 h) (7 vs 8)</td>
<td>New or progressive infiltrate on chest X-ray and purulent TA or positive blood culture without another source evidence of infection or positive pleural fluid culture and the following: T &gt;38°C and WBC &gt;10 000 (or &lt;3000) cells mm⁻³</td>
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<td>Zeitoun [42]</td>
<td>Brazil/2003</td>
<td>RCT/1</td>
<td>Medical-surgical/patients (&gt;13 yr) requiring MV &gt;48 h without AIDS or severe neutropaenia</td>
<td>47 (23 vs 24)</td>
<td>APACHE II: 22 vs 24†</td>
<td>NA/every 24 h</td>
<td>Ranitidine for stress ulcer prophylaxis/NA</td>
<td>All the following: new or progressive infiltrate on chest X-ray, purulent TA or change in their characteristics, T &gt;37.8°C, and WBC &gt;10 000 cells mm⁻³</td>
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<tr>
<td>First author [ref]</td>
<td>France/2000</td>
<td>RCT/1</td>
<td>Neurosurgical/patients requiring MV &gt;48 h without any chronic chest disease</td>
<td>104 (54 vs 50)</td>
<td>SAPS I: 7.9 (3.2) vs 6.9 (2.4)</td>
<td>Steri-Cath (Sims Portex, USA)/every 24 h</td>
<td>Stress ulcer prophylaxis/at nurse’s discretion (at least every 2 h)</td>
<td>All the following: new or progressive infiltrate on chest X-ray, purulent TA with positive sputum culture, T&gt;38°C, and WBC&gt;10 000 (or &lt;4000) cells mm⁻³</td>
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<td>Adams [1]</td>
<td>UK/1997</td>
<td>RCT/1</td>
<td>Liver/post-orthotopic liver transplant patients for chronic liver failure requiring MV &gt;28 h</td>
<td>20 (10 vs 10)</td>
<td>No differences in severity of liver disease between the compared groups</td>
<td>TrachCare (Vygon, Gloucestershire, UK)/every 24 h</td>
<td>H₂ blockers for stress ulcer prophylaxis/at nurse’s discretion (mean number of suction catheters’ passes 16.6 vs 10.0)</td>
<td>All the following: new or progressive infiltrate on chest X-ray, purulent TA, fever, abnormal gas exchange, and leucocytosis</td>
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<td>Johnson [20]</td>
<td>USA/1994</td>
<td>RCT/1</td>
<td>Trauma/patients (&gt;17 yr) requiring MV</td>
<td>35 (16 vs 19)</td>
<td>APACHE II: 12 vs 12</td>
<td>TrachCare (Ballard Medical Products, Midvale, UT)/every 24 h</td>
<td>NA/at nurse’s discretion</td>
<td>New infiltrate on chest X-ray and two of the following: purulent sputum (determined by Gram stain), T&gt;38°C, and WBC&gt;12 000 cells mm⁻³</td>
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<td>Deppe [12]</td>
<td>USA/1990</td>
<td>RCT/2</td>
<td>Medical, surgical/patients requiring MV &gt;48 h</td>
<td>84 (46 vs 38)</td>
<td>APACHE II: 22.1 (1.6) vs 25.1 (1.6) ¤</td>
<td>TrachCare (Ballard Medical Products, Midvale, UT)/every 24 h</td>
<td>H₂ blockers and antacids for stress ulcer prophylaxis/at nurse’s discretion (at least every 3 h) (16.6 vs 12.4)</td>
<td>All the following: new or progressive infiltrate on chest X-ray, purulent sputum, T&gt;38°C (or &lt;35°C), and WBC&gt;12 000 (or &lt;3000) cells mm⁻³</td>
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</table>

Table 2: Outcome data from the selected RCTs for the meta-analysis (closed vs open TSS). VAP, ventilator-associated pneumonia; ICU, intensive care unit; sd, standard deviation; MV, mechanical ventilation. *It is referred to Euros rather than USD$ in this RCT. †It is referred to colonization of the ventilator tubing rather than colonization of patients’ trachea. Ventilator tubing cultures were not obtained from all patients included in this RCT. ‡It is referred to £ rather than USD$ in this RCT.

<table>
<thead>
<tr>
<th>Primary outcome</th>
<th>Secondary outcomes</th>
<th>Cost, US$ per patient per day</th>
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</thead>
<tbody>
<tr>
<td>First author [ref]</td>
<td>Incidence of VAP, n/N (%)</td>
<td>All-cause mortality, n/N (%)</td>
</tr>
<tr>
<td>Lorente [24]</td>
<td>33/236 (14) vs 31/221 (14)</td>
<td>31/236 (13) vs 30/221 (14)</td>
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<tr>
<td>Lorente [25]</td>
<td>43/210 (21) vs 42/233 (18)</td>
<td>52/210 (25) vs 50/233 (22)</td>
</tr>
<tr>
<td>Topeli [38]</td>
<td>13/41 (32) vs 9/37 (24)</td>
<td>27/41 (66) vs 25/37 (68)</td>
</tr>
<tr>
<td>Rabitsch [29]</td>
<td>0/12 (0) vs 5/12 (42)</td>
<td>7/23 (30) vs 11/24 (46)</td>
</tr>
<tr>
<td>Zeitoun [42]</td>
<td>0/10 (0) vs 0/10 (0)</td>
<td>13/50 (26) vs 15/54 (28)</td>
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<tr>
<td>Combes [8]</td>
<td>4/50 (8) vs 9/54 (17)</td>
<td>12/46 (26) vs 11/38 (29)</td>
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<tr>
<td>Adams [1]</td>
<td>8/16 (50) vs 10/19 (53)</td>
<td>12/46 (26) vs 11/38 (29)</td>
</tr>
<tr>
<td>Deppe [12]</td>
<td>8/16 (50) vs 10/19 (53)</td>
<td>12/46 (26) vs 11/38 (29)</td>
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</table>
Length of ICU stay
Data regarding the length of ICU stay were available for two RCTs included in this meta-analysis. In both, there was no difference between the compared groups regarding ICU length of stay (Table 2).

Duration of MV
Five RCTs reported on duration of MV. Suctioning with closed as opposed to open TSS was associated with longer MV duration (WMDs: 0.65 days, 95% CI 0.28–1.03).

Colonization of the respiratory tract
Four RCTs provided data with regard to the colonization of the respiratory tract. Heterogeneity (P=0.52, I²=0, 95% CI 0–0.85) and publication bias (Egger’s test P=0.85) were not detected. More patients were colonized in the group managed with closed TSS compared with the group of patients managed with open TSS (OR=2.88, 95% CI 1.50–5.52). Regarding the potentially pathogenic micro-organisms causing colonization, specific data were provided in three of these RCTs. Colonization with Acinetobacter spp. or Pseudomonas aeruginosa was reported only in one RCT. Colonization rates with these microbes were more frequent in the closed suction group than in the open suction group (P<0.01 and P=0.01, respectively) (data not shown).

Cost
Data regarding the cost associated with each suction system were available for four RCTs. In two of these RCTs, the use of closed TSS was associated with higher cost than open TSS, whereas the remaining two RCTs reported no difference between the compared TSS regarding cost (Table 2).

Discussion
The results of this meta-analysis suggest that there is no difference between MV patients managed with closed TSS and those managed with open TSS in terms of incidence of VAP, mortality, or ICU length of stay. The findings of our study are supported by those of two reports not included in this meta-analysis; one of these reports was excluded because it was not a RCT and the other because it was only presented as an abstract. Both studies reported a similar risk for nosocomial pneumonia in both closed and open TSS.

Interestingly, the relevant guidelines seem to be inconclusive on the usefulness of closed TSS in preventing VAP in MV patients. In the most recent guidelines for preventing health-care-associated pneumonia published (2004) by the Centres for Disease Control and Prevention, the preferential use of either the closed TSS or the open TSS for VAP prevention was considered as an unresolved issue. On the other hand, the Canadian Critical Care Trials Group and the Canadian Critical Care Society (2004) concluded that type of TSS (closed or open) has no effect on VAP incidence; however, they encouraged the use of closed TSS based on cost considerations. A year earlier (2003), the American Association for Respiratory Care’s recommendation regarding this issue was that closed TSS should be considered part of a VAP prevention strategy. Finally, the European Task Force on VAP (2001) mentioned that there is only limited evidence that closed TSS usage is able to reduce VAP incidence at the expense of a clearly increased cost and, thus, no recommendation has been made.

The comparison of the various TSS with regard to physiological consequences and feasibility was not the focus of this meta-analysis. It has been demonstrated that adoption of closed rather than open TSS results in the avoidance of
effects, such as decreased arterial pressure,20 cardiac arrhythmias,20 elevated intracranial pressure,7 and arterial oxygen desaturation5 during suctioning. Although Johnson and colleagues20 reported that closed tracheal suctioning requires less nursing time than open, another study found that ICU staff experienced some difficulties when using closed TSS.2 Finally, closed TSS has been found to decrease environmental contamination.7 The latter seems to be the main advantage of closed over open TSS.10

However, the use of closed TSS has been blamed for higher levels of colonization;16 32 a concern that was confirmed by this meta-analysis. Indeed, in two12 38 of the RCTs included in the meta-analysis, closed TSS were found to increase colonization of the respiratory tract12 and of the ventilator tubing,38 respectively.

The four1 20 24 25 trials included in our meta-analysis that evaluated the cost associated with TSS reported conflicting results. Two1 25 of these trials found a higher cost in respiratory secretions’ suctioning with the use of closed TSS than with open ones, whereas the other two20 24 found no difference. However, one20 was published in 1994, and therefore the cost data are now out of date. In the other,24 the cost of closed TSS was presumably reduced by the avoidance of routine (every 24 h) in-line suction catheter changes.35 Indeed, relevant guidelines agree that closed TSS catheters should be replaced only when it is clinically indicated.14 18 39

The present meta-analysis is not without limitations. First, there are relatively few trials to review and none was blinded; thus, one might postulate that our analysis may be not powered enough to detect a difference between the two techniques of endotracheal suctioning. However, we deliberately chose to include only RCTs, which are considered to provide the most methodologically rigorous evidence, and we accepted the lack of blindness as inevitable in this case due to the nature of the intervention. Secondly, the criteria used for the definition of VAP were not identical in the investigations included in this meta-analysis. Therefore, this may have introduced significant confounding. Thirdly, the differences in the populations studied in the selected RCTs may also confound the results of any meta-analysis of VAP. Thus, we performed a subgroup analysis by excluding the RCT that enrolled only liver-transplant patients.3 Finally, the fact that the included trials were conducted in different time periods and, thus, routine care and co-interventions for VAP prevention may be not identical may also introduce problems in the interpretation of the findings and their application. However, subgroup analyses were again performed by pooling data from trials before1 8 12 20 and after24 25 29 38 42 2003.

The findings of this meta-analysis corroborate those of two very recently analyses that investigated the use of closed vs open TSS.21 40 The first analysis was limited to the evaluation of the impact on the incidence of VAP,40 whereas the other focused mainly on the cardiorespiratory effects in MV patients.21 Our contribution differs in that it also includes analysis of duration of MV, specific data on the length of ICU stay, and the kind of micro-organisms causing colonization. This additional information, in combination with the above studies, permits a more comprehensive estimation of the different techniques of endotracheal suctioning.

In conclusion, the use of closed TSS is not associated with lower incidence of VAP or mortality compared with open TSS. We should emphasize that as this intervention has been proved not to be harmful, further investigation is warranted to clarify its potential value in decreasing environmental spread of multi-drug resistant pathogens, an issue of major importance.

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