Care of the Ventilator Circuit and Its Relation to Ventilator-Associated Pneumonia

Summary of Recommendations

- **Ventilator circuits should not be changed routinely for infection control purposes. The maximum duration of time that circuits can be used safely is unknown.**
- **Evidence is lacking related to ventilator-associated pneumonia (VAP) and issues of heated versus unheated circuits, type of heated humidifier, method for filling the humidifier, and technique for clearing condensate from the ventilator circuit.**
- **Although the available evidence suggests a lower VAP rate with passive humidification than with active humidification, other issues related to the use of passive humidifiers (resistance, dead space volume, airway occlusion risk) preclude a recommendation for the general use of passive humidifiers.**
- **Passive humidifiers do not need to be changed daily for reasons of infection control or technical performance. They can be safely used for at least 48 hours, and with some patient populations some devices may be able to be used for periods of up to 1 week.**
- **The use of closed suction catheters should be considered part of a VAP prevention strategy, and they do not need to be changed daily for infection control purposes. The maximum duration of time that closed suction catheters can be used safely is unknown.**
- **Clinicians caring for mechanically ventilated patients should be aware of risk factors for VAP (eg, nebulizer therapy, manual ventilation, and patient transport).** [Respir Care 2003;48(9):869–879. © 2003 Daedalus Enterprises]

Introduction

A concern related to the care of the mechanically ventilated patient is the development of VAP. For many years this concern focused on the ventilator circuit and humidifier. Accordingly, the circuit and humidifier have been changed on a regular basis in an attempt to decrease the VAP rate. However, as the evidence evolved, it became apparent that the origin of VAP is more likely from sites other than the ventilator circuit,[1,2] and thus the prevailing practice has become one of changing circuits less frequently.[3] If this practice is safe, it will offer substantial cost savings. Other issues related to the components of the circuit and VAP have also become more important recently. For example, humidification systems can be either active or passive. Increasingly, inline suction is used, and this becomes part of the ventilator circuit.

A systematic review of the literature was conducted with the intention of making recommendations for change frequency of the ventilator circuit and additional components of the circuit. Specifically, the Writing Committee wrote these evidence-based clinical practice guidelines to address the following questions:

1. Do ventilator circuits need to be changed at regular intervals:
   a. For infection control purposes?
   b. Because of deterioration in performance?
2. What is the economic impact of decreasing the frequency of ventilator circuit changes?
3. What are the issues related to circuit type?
   a. Disposable versus reusable
   b. Cleaning techniques
   c. Site of care (acute care, long-term care, home care)
4. Does the choice of active versus passive humidification affect ventilator circuit change frequency?
5. Do passive humidifiers need to be changed at regular intervals:
   a. For infection control purposes?
   b. Because of deterioration in performance?

Principal author: Dean R Hess PhD RRT FAARC. *Writing committee*: Thomas J Kallstrom RRT FAARC, Carl D Mottram RRT FAARC, Timothy R Myers RRT-NPS, Helen M Sorenson MA RRT FAARC, and David L Vines MHS RRT.

Correspondence: Dean R Hess PhD RRT FAARC, Respiratory Care, Ellison 401, Massachusetts General Hospital, 55 Fruit Street, Boston MA 02114. E-mail: dhess@partners.org.

6. Do in-line suction catheters need to be changed at regular intervals:
   a. For infection control purposes?
   b. Because of deterioration in performance?
7. Are there specific populations for which the recommendations should be altered?
   a. Differences for age groups (neonatal, pediatric, adult)
   b. Differences for site of care (acute care, long-term care, home care)
   c. Differences for categories of patients (immunocompromised, burn)

Methods

To identify the evidence for addressing these questions, a PubMed (MEDLINE) search was conducted using the following search terms: pneumonia AND mechanical ventilation, humidifier, ventilator circuit, heated circuit, suction catheter, endotracheal suction, closed suction catheter, respiratory therapy equipment, endotracheal intubation, heat and moisture exchanger, tracheostomy, respiratory care, equipment contamination, equipment disinfection, artificial ventilation. The search was confined to human studies published in the English language. References and abstracts were retrieved into reference management software (EndNote, ISI, Berkeley, California). By inspection of these titles, references having no relevance to the study questions were eliminated. For the titles that remained, the abstracts were assessed for relevance and additional references were eliminated as appropriate. This process was conducted independently by 2 individuals, after which their reference lists were merged to provide the reference base for further analysis. Throughout the process of developing these guidelines, members of the Writing Committee surveyed cross-references to identify additional references to be added to the reference base for analysis.

Data were extracted from selected references using a standardized critique form. To validate this form and to establish the reliability of the review process, several references were evaluated by the entire committee during a face-to-face meeting. All references were then independently examined by at least 2 members of the Writing Committee. The critiques were compared and differences were resolved using an iterative process. All references were graded according to the following scheme:

Level 1: Randomized, controlled trial with statistically significant results
Level 2: Randomized, controlled trial with significant threats to validity (eg, small sample size, inappropriate blinding, weak methodology)
Level 3: Observational study with a concurrent control group
Level 4: Observational study with a historical control group
Level 5: Bench study, animal study, case series

The critique forms were submitted to the principal author of the guideline (DRH), who transferred the information into evidence tables and conducted appropriate statistical analysis.

Quantitative analysis consisted of meta-analysis and petograms. Statistical analysis was conducted using RevMan software (RevMan Analyses, Version 1.0 for Windows, in Review Manager [RevMan] 4.2, Oxford, England: The Cochrane Collaboration, 2003). Relative risk was calculated using a random effect model. $P < 0.05$ was considered statistically significant. Following a systematic review of the literature, recommendations were drafted by the Writing Committee and assigned one of the following grades, based on the strength of the evidence:

Grade A: Scientific evidence provided by randomized, well-designed, well-conducted, controlled trials with statistically significant results that consistently support the guideline recommendation; supported by Level 1 or 2 evidence
Grade B: Scientific evidence provided by well-designed, well-conducted observational studies with statistically significant results that consistently support the guideline recommendation; supported by Level 3 or 4 evidence
Grade C: Scientific evidence from bench studies, animal studies, case studies; supported by Level 5 evidence
Grade D: Expert opinion provides the basis for the guideline recommendation, but scientific evidence either provided inconsistent results or was lacking

The draft document was then reviewed by experts on ventilator circuit care. Each of the reviewer's comments was carefully assessed and the document was further revised as appropriate.

Do Ventilator Circuits Need to Be Changed at Regular Intervals?

Based on studies published in the 1960s that showed an association between respiratory equipment and nosocomial pneumonia,[4,5] the practice of changing ventilator circuits at least daily was established. In fact, circuits were changed every 8 hours in some hospitals, in an attempt to reduce the incidence of VAP. This practice was challenged in a landmark study published by Craven et al in 1982.[6] In that study 240 cultures of inspiratory-phase gas were obtained from 95 patients. There was no significant difference in the frequency of positive cultures in circuits changed

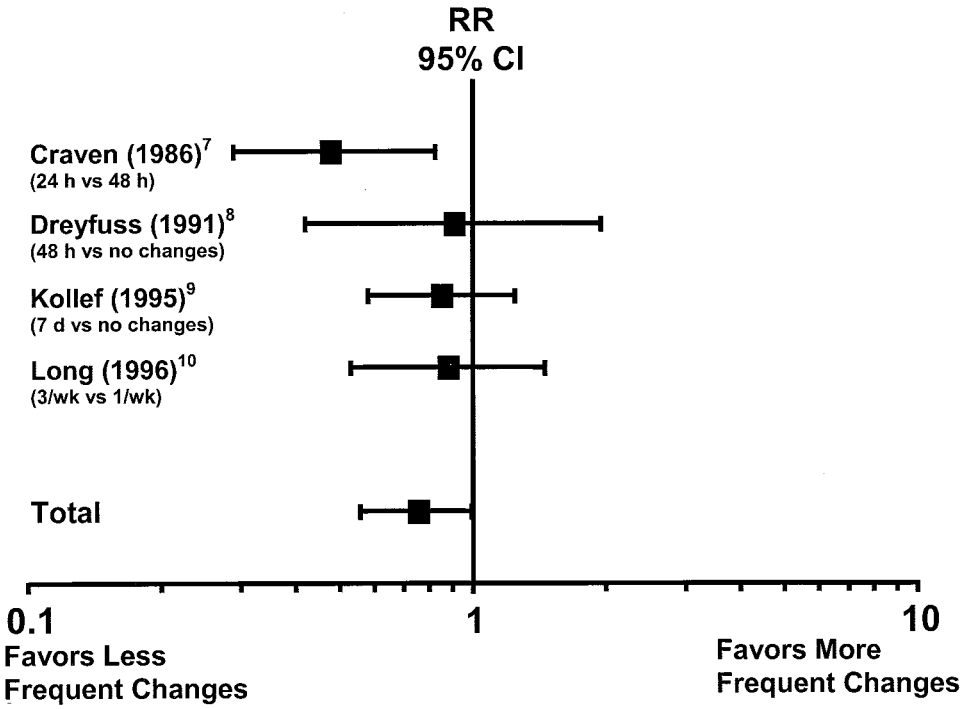

Fig. 1. Randomized, controlled trials of the relationship between ventilator circuit change frequency and the risk of ventilator-associated pneumonia. RR = relative risk. CI = confidence interval.

every 24 hours (30%) and in circuits changed every 48 hours (32%). Moreover, no significant increase in circuit colonization occurred between 24 and 48 hours. Based on that study, most hospitals in the United States adopted the practice of changing ventilator circuits at 48-hour intervals. Craven et al estimated that $300,000 (in 1982 dollars) would be saved at 20 Boston teaching hospitals by adopting this practice. Interestingly, Craven et al did not report VAP rates in their study.

The effect of ventilator circuit change interval on VAP rate was assessed in 4 prospective randomized, controlled trials (Table 1 and Fig. 1).[7–10] Although each of these

Table 1. Summary of Randomized Controlled Trials Investigating the Relationship Between Ventilator Circuit Change Frequency and the Risk of Ventilator-Associated Pneumonia

Citation	Study Population	Blinding	VAP Diagnosis	Control Group	Treatment Group	Control Group		Treatment Group		Level	Relative Risk (95% CI)
						n	Pneumonia (%)	*n*	Pneumonia (%)		
Craven 1986[7]	Adult patients requiring mechanical ventilation > 48 h	VAP assessors	Clinical	Circuit changes every 24 h	Circuit changes every 48 h	106	29.2	127	14.2	1	0.48 (0.29, 0.82)
Dreyfuss 1991[8]	Adult patients requiring mechanical ventilation > 48 h	VAP assessors	Quantitative cultures	Circuit changes every 48 h	No circuit changes	35	31.4	28	28.5	1	0.91 (0.42, 1.95)
Kollef 1995[9]	Adult patients requiring mechanical ventilation > 5 d	VAP assessors	Clinical	Circuit changes every 7 d	No circuit changes	153	28.8	147	24.5	1	0.85 (0.58, 1.24)
Long 1996[10]	Neonatal and adult mechanically ventilated patients	None	Clinical	Circuit changes 3 times/wk	Circuit change 1/wk	213	12.7	234	11.1	2	0.88 (0.53, 1.45)
TOTAL						507	22.3	536	16.4		0.76 (0.57, 1.00)

VAP = ventilator-associated pneumonia.
CI = confidence interval.

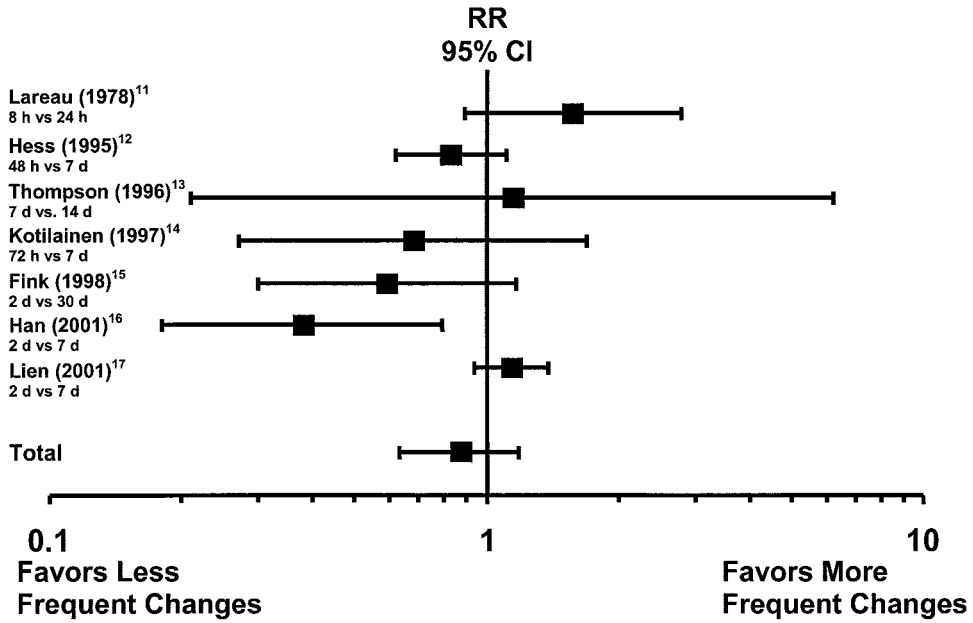

Fig. 2. Observational studies of the relationship between ventilator circuit change frequency and the risk of ventilator-associated pneumonia. RR = relative risk. CI = confidence interval.

studies evaluated different circuit change intervals, the combined effect supports the practice of less frequent circuit changes (relative risk 0.76, 95% confidence interval [CI] 0.57 to 1.00, p = 0.05). In each of these studies, the risk of VAP was decreased when circuits were changed less frequently. Ventilator circuit change interval was also assessed in 7 studies with historical control groups (Table 2 and Fig. 2).[11–17] Again, the combined effect supports the practice of less frequent circuit changes (relative risk 0.87, 95% CI 0.63 to 1.18, p = 0.37). Two well-designed randomized, controlled trials evaluated the practice of "no changes" of ventilator circuits.[8,9] However, the maximum duration of time that the circuit can be used safely is unknown. In one of those studies, the maximum duration of use of a circuit was 29 days.[8] The other study did not report the maximum duration of use of a circuit but did report that 35% of patients were ventilated for > 14 days.[9]

The costs associated with ventilator circuit changes were calculated in 8 studies.[6,8,9,12–15,17] Because these studies were conducted over a span of 20 years and in different countries, direct cost comparisons are difficult. Not surprisingly, each of these studies suggests considerable savings in personnel and materials costs with less frequent ventilator circuit changes. One study evaluated equipment failure (circuit leaks) related to ventilator circuit change frequency.[9] In that study there was no significant difference in equipment failures when circuits were changed at weekly intervals and when circuits were not changed at regular intervals.

The majority of the studies were in adult patients in acute care units. One study was conducted in a subacute care unit.[13] Two studies included neonatal and pediatric mechanically ventilated patients.[10,11] Although ventilator circuit change interval has been studied less in patient groups other than adult patients in acute care units, the available evidence suggests no increased risk for VAP associated with infrequent circuit changes in these populations. There have been no studies that separately addressed special populations such as immunocompromised or burned patients.

Recommendation #1. Ventilator circuits should not be changed routinely for infection control purposes. The available evidence suggests no patient harm and considerable cost savings associated with extended ventilator circuit change intervals. The maximum duration of time that circuits can be used safely is unknown. (Grade A)

Most studies used heated passover humidifiers, although several used bursting-bubble cascade-type humidifiers.[8,12,17] There is concern related to the use of bursting-bubble humidifiers because these have shown the potential to generate aerosols capable of carrying microorganisms.[18,19] However, this is not a consideration in the present day, as these devices are no longer

Table 2. Summary of Observational Studies Investigating the Relationship Between Ventilator Circuit Change Frequency and the Risk of Ventilator-Associated Pneumonia

Citation	Study Population	VAP Diagnosis	Control Group	Treatment Group	Control Group		Treatment Group		Level	Relative Risk (95% CI)
					n	Pneumonia (%)	*n*	Pneumonia (%)		
Lareau 1978[11]	Adult, pediatric, and neonatal mechanically ventilated patients	Clinical	Circuit changes at 8-h intervals	Circuit changes at 24-h intervals	213	7.5	271	11.8	4	1.57 (0.89, 2.79)
Hess 1995[12]	Adult mechanically ventilated patients	Clinical	Circuit changes at 2-d intervals	Circuit changes at 7-d intervals	1,708	5.6	1,715	4.6	4	0.83 (0.62, 1.11)
Thompson 1996[13]	Adult mechanically ventilated patients in a subacute care facility	Clinical	Circuit changes at 7-d intervals	Circuit changes at 14-d intervals	31	9.7	18	11.1	4	1.15 (0.21, 6.24)
Kotilainen 1997[14]	Adult mechanically ventilated patients	Clinical	Circuit changes at 3-d intervals	Circuit changes at 7-d intervals	88	9.1	146	6.2	4	0.68 (0.27, 1.69)
Fink 1998[15]	Adult mechanically ventilated patients	Clinical	Circuit changes at 2-d intervals	Circuit changes at 30-d intervals	336	10.7	157	6.4	4	0.59 (0.30, 1.17)
Han 2001[16]	Adult mechanically ventilated patients	Clinical	Circuit changes at 2-d intervals	Circuit changes at 7-d intervals	413	9.2	231	3.5	4	0.38 (0.18, 0.79)
Lien 2001[17]	Adult mechanically ventilated patients	Clinical	Circuit changes at 2-d intervals	Circuit changes at 7-d intervals	6,213	2.9	7,068	3.2	4	1.14 (0.94, 1.38)
Total					9,002	4.1	9,606	3.8		0.87 (0.63, 1.18)

VAP = ventilator-associated pneumonia.
CI = confidence interval.

commercially available. Moreover, bacterial levels in heated humidifiers are low and nosocomial pathogens survive poorly in this environment.[20] Although a few studies used reusable circuits,[11,17] most used disposable circuits. In several studies, heated-wire circuits were used.[10,14–16] One small study[21] compared heated-wire circuits and nonheated-wire circuits and found no difference in VAP rate (relative risk 1.57 in favor of nonheated-wire circuits, 95% CI 0.55 to 4.45). The condensate that accumulates in the ventilator circuit is contaminated,[22] and care should be taken to avoid its cross-contamination of other patients. Although it makes sense that care should be taken to avoid breaking the circuit—which could contaminate the interior of the ventilator circuit—this has not been studied. One observational study compared daily with biweekly circuit changes with the use of a passive humidifier and reported no change in VAP rate with the longer circuit change interval.[23] Another study compared disposable and reusable humidifiers during mechanical ventilation, and reported no difference in VAP.[24] It is fair to say that the risk of VAP is not increased by less frequent circuit changes, despite a variety of practices related to the type of circuit used and the care of the circuit. Standard practice calls for use of sterile water in the humidifier of the ventilator circuit. Because water is an important reservoir for nosocomial pathogens and there has been no published study of this topic using modern humidification systems, the practice of filling humidifiers with sterile water appears appropriate.

Recommendation #2. Evidence is lacking related to VAP and issues of heated versus unheated circuits, type of heated humidifier, method for filling the humidifier, and technique for clearing condensate from the ventilator circuit. It is prudent to avoid excessive accumulation of condensate in the circuit. Care should be taken to avoid accidental drainage of condensate into the patient's airway and to avoid contamination of caregivers during ventilator disconnection or during disposal of condensate. Care should be taken to avoid breaking the ventilator circuit, which could contaminate the interior of the circuit. (Grade D)

Is Ventilator-Associated Pneumonia Rate Affected By the Choice of Active Versus Passive Humidification in Mechanically Ventilated Patients?

Humidification of the inspired gas is a standard practice in the care of mechanically ventilated patients. Humidifiers can be active or passive. Active humidifiers pass the inspired gas either through (bubble) or over (passover,

wick) a heated water bath. Passive humidifiers (artificial nose, heat-and-moisture exchanger) trap heat and humidity from the patient's exhaled gas and return some of that to the patient on the subsequent inhalation. By its nature the ventilator circuit remains dry with the use of a passive humidifier. Passive humidifiers also have filtering characteristics, and some are constructed specifically to function as filters as well as humidifiers. The performance of humidification systems has been described in detail elsewhere.[25]

Because passive humidifiers maintain a dry circuit and have filtering properties, there has been much interest in their potential to decrease the incidence of VAP. Indeed, several studies have reported that circuit contamination is reduced with the use of passive humidifiers.[26–31] One study reported similar tracheal colonization rates with active and passive humidifiers.[32] The VAP rate with passive versus active humidification was addressed in 6 studies (Table 3).[21,33–37] The combined results of these studies (Fig. 3) indicate a lower risk of VAP with the use of passive humidification (relative risk 0.65, 95% CI 0.44 to 0.96, p = 0.03). Although the combined effect from this meta-analysis shows a statistically lower VAP for the use of passive humidifiers, it is of interest to note that only one of the studies[36] reported a significant reduction in VAP with the use of passive humidifiers. These studies used various brands of passive humidifier, all were conducted with adult patients, and all were conducted in the acute care setting. Two studies reported no significant difference in the VAP rate when comparing designs of passive humidifiers (different components, hydrophobic vs hygroscopic).[38,39]

In addition to VAP, there are other important issues that must be considered when a passive humidifier is used. These include the dead space of the device, the resistive load of the device, the difficulty in delivery of aerosolized medications, and the potential for airway occlusion. An increased work-of-breathing attributable to the use of a passive humidifier has been reported.[40] The use of a passive humidifier has been associated with higher P_{aCO_2} and higher minute ventilation requirement.[41] Another study reported significant reduction in P_{aCO_2} with removal of the passive humidifier in patients receiving lung-protective ventilation.[42] Of considerable concern is the increased risk of airway occlusion when a passive humidifier is used. In one study[33] the use of passive humidifiers was interrupted because of a fatal occlusion of the airway. Other studies have also reported greater risk of airway occlusion with the use of a passive humidifier.[34,43,44] A meta-analysis of airway occlusion associated with the use of passive humidifier reported a relative risk of 3.84 (95% CI 1.92 to 7.69, p = 0.0001), favoring the use of active humidification (ie, indicating a significantly greater risk of airway occlusion with a passive humidifier).[45] When a passive humidifier is used, it is important that one be selected that has an adequate moisture output, to minimize the risk of airway occlusion.

Table 3. Summary of Randomized Controlled Trials Investigating the Relationship Between Type of Humidification and the Risk of Ventilator-Associated Pneumonia

Citation	Study Population	VAP Diagnosis	Passive humidifier	Active Humidifier		Passive Humidifier		Level	Relative Risk (95% CI)
				n	Pneumonia (%)	*n*	Pneumonia (%)		
Martin 1990[33]	Adult mechanically ventilated patients	Clinical	Pall Ultipor breathing circuit filter	42	19.0	31	6.5	2	0.34 (0.08, 1.49)
Roustan 1992[34]	Adult mechanically ventilated patients	Clinical	Pall BB 2215	61	14.8	55	9.1	1	0.62 (0.22, 1.73)
Dreyfuss 1995[35]	Adult mechanically ventilated patients	Quantitative cultures	DAR Hygrobac II	70	11.4	61	9.8	1	0.86 (0.32, 2.34)
Branson 1996[21]	Adult mechanically ventilated patients	Clinical	Baxter nonfiltered hygroscopic condenser humidifier	54	5.6	49	6.1	2	1.10 (0.23, 5.21)
Kirton 1997[36]	Adult mechanically ventilated patients	Clinical	Pall BB-100	140	15.7	140	6.4	2	0.41 (0.20, 0.86)
Kollef 1998[37]	Adult mechanically ventilated patients	Clinical	Nellcor-Puritan-Bennett hygroscopic condenser humidifier	147	10.2	163	9.2	1	0.90 (0.46, 1.78)
Total				514	12.6	499	8.0		0.65 (0.44, 0.96)

VAP = ventilator-associated pneumonia.
CI = confidence interval.

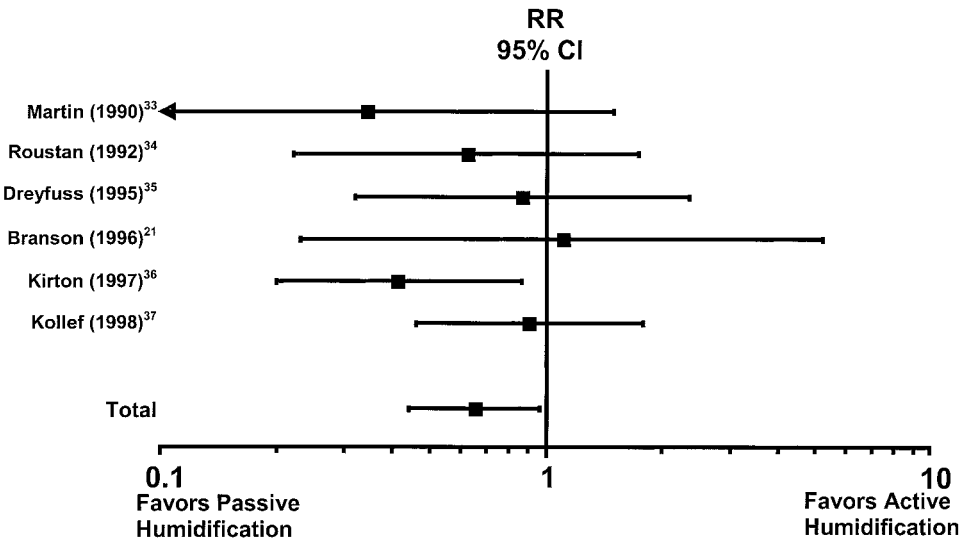

Fig. 3. Randomized, controlled trials of the relationship between type of humidification and the risk of ventilator-associated pneumonia. RR = relative risk. CI = confidence interval.

Recommendation #3. Although the available evidence suggests a lower VAP rate with passive humidification than with active humidification, other issues related to the use of passive humidifiers (resistance, dead space volume, airway occlusion risk) preclude a recommendation for the general use of these devices. The decision to use a passive humidifier should not be based solely on infection control considerations. (Grade A)

Do Passive Humidifiers Need to Be Changed at Regular Intervals?

The manufacturers of passive humidifiers typically recommend that they be changed at daily intervals. There has been interest in the safety of changing these devices less frequently, both in terms of VAP rate and device performance. Two randomized, controlled trials[46,47] and 2 observational studies compared daily versus less frequent changes of passive humidifiers (Table 4).[48,49] In 2 studies passive humidifiers were changed at 48-hour intervals,[48,49] in a separate study they were changed at 5-day intervals,[46] and in another study they were changed at 7-day intervals.[47] For the pooled results (Fig. 4), no significant difference in VAP rate was found with less frequent changes of passive humidifiers, in either the randomized, controlled studies (relative risk 0.58, 95% CI 0.24 to 1.41, p = 0.14) or the observational studies (relative risk 1.13, 95% CI 0.73 to 1.76, p = 0.9). Other studies have evaluated the technical performance of passive humidifiers used for durations up to 48 hours,[50–52] 96 hours,[53–55] and 7 days.[56] However, caution has been suggested related to prolonged use of passive humidifiers with some devices[52,57] and in some patient populations (eg, chronic obstructive pulmonary disease).[56] Based on the available evidence, it seems prudent to closely monitor the technical performance of these devices if used longer than 48 hours.

Recommendation #4. Passive humidifiers do not need to be changed daily for reasons of infection control or technical performance. They can be safely used for at least 48 hours, and with some patient populations some devices may be able to be used for up to 1 week. (Grade A)

Do In-Line Suction Catheters Need to Be Changed at Regular Intervals?

In-line closed suction systems allow mechanically ventilated patients to be suctioned without removal of ventilator support. This may decrease the complications associated with suctioning[58] and might prevent alveolar derecruitment during suctioning.[59,60] One study reported significantly less environmental contamination with closed suctioning than with open suctioning.[61] Observational studies report high levels of contamination in closed suction catheters that are in use.[62,63] However, this contamination usually arises from the endotracheal tube and the patient's lower respiratory tract. Accordingly, the patient usually contaminates the catheter, rather than vice versa. Use of closed suctioning has been recommended as part of a VAP-prevention program.[64] Two prospective, randomized, controlled trials reported similar VAP rates with closed suctioning and open suctioning.[58,65] Another study, however, reported a 3.5 times greater risk of VAP in patients randomized to receive open suctioning than those receiving closed suctioning.[66] Although the available evidence is not conclusive that closed suctioning decreases the risk of VAP,

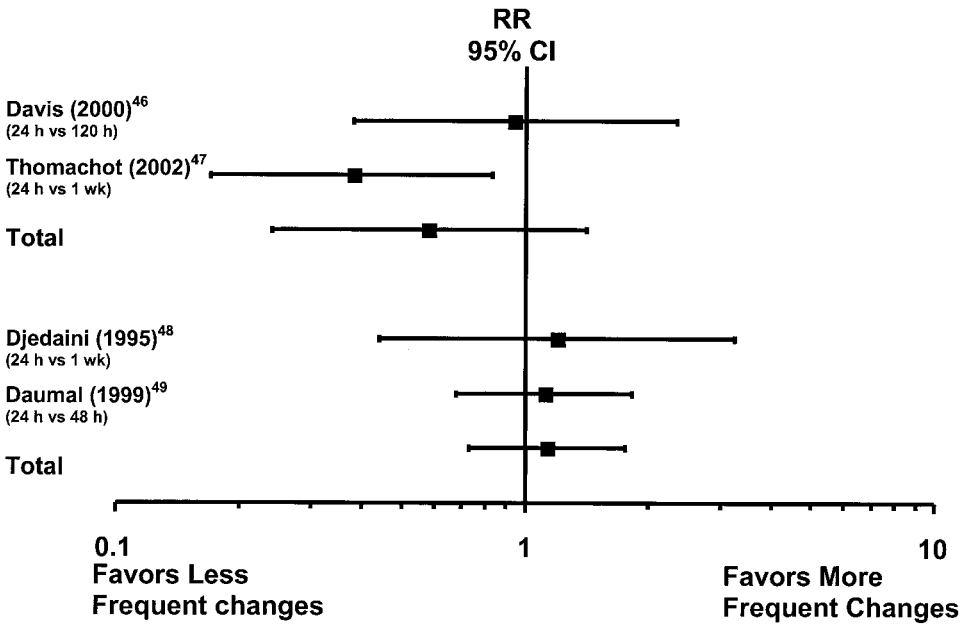

Fig. 4. Studies of the relationship between passive humidifier change frequency and the risk of ventilator-associated pneumonia. RR = relative risk. CI = confidence interval.

Table 4. Summary of Studies Investigating the Relationship Between Change Frequency for Passive Humidifiers and the Risk of Ventilator-Associated Pneumonia

Citation	Study Population	VAP Diagnosis	Control Group	Treatment Group	Control Group		Treatment Group		Level	Relative Risk (95% CI)
					n	Pneumonia (%)	*n*	Pneumonia (%)		
Randomized Controlled Trials										
Davis 2000[46]	Adult mechanically ventilated patients	Clinical	HME changed every 24 h	HME changed every 120 h	100	8.0	120	7.5	1	0.94 (0.38, 2.34)
Thomachot 2002[47]	Adult mechanically ventilated patients	Clinical	HME changed every 24 h	HME changed every 7 d	84	26.2	71	9.9	1	0.38 (0.17, 0.83)
Total					184	16.3	191	8.4		0.58 (0.24, 1.41)
Observational Studies										
Djedaini 1995[48]	Adult mechanically ventilated patients	Quantitative cultures	HME changed every 24 h	HME changed every 48 h	61	9.8	68	11.8	4	1.20 (0.44, 3.25)
Daumal 1999[49]	Adult mechanically ventilated patients	Quantitative cultures	HME changed every 24 h	HME changed every 48 h	174	14.4	187	16.0	4	1.12 (0.68, 1.82)
Total					235	13.2	255	14.9		1.13 (0.73, 1.76)

VAP = ventilator-associated pneumonia.
CI = confidence interval.
HME = heat and moisture exchanger.

there is no high-level evidence that use of closed suction catheters increases the risk of VAP.

The in-line closed suction catheter might be considered an extension of the ventilator circuit. Because ventilator circuits do not need to be changed at regular intervals for infection control purposes, this might suggest that in-line suction catheters also do not need to be changed at regular intervals for infection control purposes. Although the manufacturers of in-line suction catheters recommend that these devices be changed at regular intervals, there is accumulating evidence that they might not need to be changed routinely. One observational study reported no change in VAP rate when in-line suction catheters were changed on a weekly rather than daily basis.[67] Another study reported no significant difference in VAP rate between patients randomized to receive daily changes of the in-line suction catheter and those with whom there were no routine changes of the in-line catheter

(relative risk 0.99, 95% CI 0.66 to 1.50).[68] The maximum duration of use of a closed suction catheter in that study was 67 days. There were few device malfunctions when in-line catheters were changed less frequently than daily, and there were important cost savings associated with this practice.[67,68] As with ventilator circuits, the maximum duration that closed suction catheters can be used safely is not known.

Recommendation #5. The use of closed suction catheters should be considered part of a VAP prevention strategy. When closed suction catheters are used, they do not need to be changed daily for infection control purposes. The maximum duration of time that closed suction catheters can be used safely is unknown. (Grade A)

Other Issues

Other issues related to the technical aspects of mechanical ventilation may be important in relation to VAP. Medication nebulizers can be a source of contamination that could lead to VAP.[69] Accordingly, with nebulizers care must be taken to avoid contamination of the ventilator circuit and the patient's respiratory tract. It is commonly believed by respiratory therapists that the risk of ventilator circuit contamination is reduced with the use of metered-dose inhalers, but this has not been reported. Manual ventilator devices that are commonly kept at the bedside of mechanically ventilated patients have been shown to be a source of airway contamination, so care should be taken to minimize the potential infection risks associated with manual ventilator devices.[70,71] One study reported a significantly greater likelihood of VAP among patients who underwent transport out of the intensive care unit for diagnostic, surgical, or miscellaneous interventions (odds ratio 3.8, 95% CI 2.6 to 5.5, $p < 0.001$).[72] Because a VAP risk education program for respiratory therapists and critical care nurses decreased the incidence of VAP,[73] VAP risk education should be widely implemented.

Recommendation # 6. Clinicians (respiratory therapists, nurses, and physicians) caring for mechanically ventilated patients should be aware of risk factors for VAP (eg, nebulizer therapy, manual ventilation, and patient transport). (Grade B)

Discussion

Substantial evidence now exists to make recommendations related to the technical practices of mechanical ventilation and the risk of VAP. However, important gaps also exist in this evidence base. For example, most of the published evidence comes from studies of adult patients. Few data have been published for neonatal and pediatric populations. In addition most studies come from the acute care setting. Finally, there has been little research done on important subgroups of patients, such as immunocompromised patients. Accordingly, much remains to be learned about important relationships between the technical aspects of mechanical ventilation and the risk of VAP. Thus, these evidence-based guidelines provide not only a basis for current practice but are also a framework for further investigation.

REFERENCES

1. Cook D, De Jonghe B, Brochard L, Brun-Buisson C. Influence of airway management on ventilator-associated pneumonia: evidence from randomized trials. JAMA 1998;279(10):781–787. Erratum in: JAMA 1999;281(22):2089
2. Cook DJ, Walter SD, Cook RJ, Griffith LE, Guyatt GH, Leasa D, et al. Incidence of and risk factors for ventilator-associated pneumonia in critically ill patients. Ann Intern Med 1998;129(6):433–440.
3. Cook D, Ricard JD, Reeve B, Randall J, Wigg M, Brochard L, Dreyfuss D. Ventilator circuit and secretion management strategies: a Franco-Canadian survey. Crit Care Med 2000;28(10):3547–3554.
4. Reinarz JA, Pierce AK, Mays BB, Sanford JP. The potential role of inhalation therapy equipment in nosocomial pulmonary infection. J Clin Invest 1965;44:831–839.
5. Edmondson EB, Reinarz JA, Pierce AK, Sanford JP. Nebulization equipment: a potential source of infection in gram-negative pneumonias. Am J Dis Child 1966;111(4):357–360.
6. Craven DE, Connolly MG Jr, Lichtenberg DA, Primeau PJ, McCabe WR. Contamination of mechanical ventilators with tubing changes every 24 or 48 hours. N Engl J Med 1982;306(25):1505–1509.
7. Craven DE, Kunches LM, Kilinsky V, Lichtenberg DA, Make BJ, McCabe WR. Risk factors for pneumonia and fatality in patients receiving continuous mechanical ventilation. Am Rev Respir Dis 1986;133(5):792–796.
8. Dreyfuss D, Djedaini K, Weber P, Brun P, Lanore JJ, Rahmani J, et al. Prospective study of nosocomial pneumonia and of patient and circuit colonization during mechanical ventilation with circuit changes every 48 hours versus no change. Am Rev Respir Dis 1991;143(4 Pt 1):738–743.
9. Kollef MH, Shapiro SD, Fraser VJ, Silver P, Murphy DM, Trovillion E, et al. Mechanical ventilation with or without 7-day circuit changes. A randomized, controlled trial. Ann Intern Med 1995;123(3):168–174.
10. Long MN, Wickstrom G, Grimes A, Benton CF, Belcher B, Stamm AM. Prospective, randomized study of ventilator-associated pneumonia in patients with one versus 3 ventilator circuit changes per week. Infect Control Hosp Epidemiol 1996;17(1):14–19.
11. Lareau SC, Ryan KJ, Diener CF. The relationship between frequency of ventilator circuit changes and infectious hazard. Am Rev Respir Dis 1978;118(3):493–496.
12. Hess D, Burns E, Romagnoli D, Kacmarek RM. Weekly ventilator circuit changes: a strategy to reduce costs without affecting pneumonia rates. Anesthesiology 1995;82(4):903–911.
13. Thompson RE. Incidence of ventilator-associated pneumonia (VAP) with 14-day circuit change in a subacute environment. Respir Care 1996;41(7):601–606.
14. Kotilainen HR, Keroack MA. Cost analysis and clinical impact of weekly ventilator circuit changes in patients in intensive care unit. Am J Infect Control 1997;25(2):117–120.

15. Fink JB, Krause SA, Barrett L, Schaaff D, Alex CG. Extending ventilator circuit change interval beyond 2 days reduces the likelihood of ventilator-associated pneumonia. Chest 1998;113(2):405–411.
16. Han JN, Liu YP, Ma S, Zhu YJ, Sui SH, Chen XJ et al. Effects of decreasing the frequency of ventilator circuit changes to every 7 days on the rate of ventilator-associated pneumonia in a Beijing hospital. Respir Care 2001;46(9):891–896.
17. Lien TC, Lin MY, Chu CC, Kuo BI, Wang ED, Wang JH. Ventilator-associated pneumonia with circuit changes every 2 days versus every week. Zhonghua Yi Xue Za Zhi (Taipei) 2001;64(3):161–167.
18. Rhame FS, Streifel A, McComb C, Boyle M. Bubbling humidifiers produce microaerosols which can carry bacteria. Infect Control 1986; 7(8):403–407.
19. Gilmour IJ, Boyle MJ, Streifel A, McComb RC. The effects of circuit and humidifier type on contamination potential during mechanical ventilation: a laboratory study. Am J Infect Control 1995; 23(2):65–72.
20. Goularte TA, Manning M, Craven DE. Bacterial colonization in humidifying cascade reservoirs after 24 and 48 hours of continuous mechanical ventilation. Infect Control 1987;8(5):200–203.
21. Branson RD, Davis K Jr, Brown R, Rashkin M. Comparison of 3 humidification techniques during mechanical ventilation: patient selection, cost, and infection considerations. Respir Care 1996;41(9): 809–816.
22. Craven DE, Goularte TA, Make BJ. Contaminated condensate in mechanical ventilator circuits: a risk factor for nosocomial pneumonia? Am Rev Respir Dis 1984;129(4):625–628.
23. Salemi C, Padilla S, Canola T, Reynolds D. Heat-and-moisture exchangers used with biweekly circuit tubing changes: effect on costs and pneumonia rates. Infect Control Hosp Epidemiol 2000;21(11): 737–739.
24. Daschner F, Kappstein I, Schuster F, Scholz R, Bauer E, Joossens D, Just H. Influence of disposable ('Conchapak') and reusable humidifying systems on the incidence of ventilation pneumonia. J Hosp Infect 1988;11(2):161–168.
25. Branson RD, Campbell RS. Humidification in the intensive care unit. Respir Care Clin N Am 1998;4(2):305–320.
26. Gallagher J, Strangeways JEM, Allt-Graham J. Contamination control in long-term ventilation: a clinical study using a heat- and moisture- exchanging filter. Anaesthesia 1987;42(5):476–481.
27. Cadwallader HL, Bradley CR, Ayliffe GAJ. Bacterial contamination and frequency of changing ventilator circuitry. J Hosp Infect 1990; 15(1):65–72.
28. Strange K, Bygdeman S. Do moisture exchangers prevent patient contamination of ventilators? A microbiological study comparing 2 different humidifying devices. Acta Anaesthesiol Scand 1980;24(6): 487–490.
29. Saravolatz LD, Pohlod DJ, Conway W, Haberaecker W, Markowitz NP, Popovich J Jr. Lack of bacterial aerosols associated with heat and moisture exchangers. Am Rev Respir Dis 1986;134(2):214–216.
30. Bygdeman S, von Euler C, Nystrom B. Moisture exchangers do not prevent patient contamination of ventilators: a microbiological study. Acta Anaesthesiol Scand 1984;28(6):591–594.
31. Das I, Fraise AP. How useful are microbial filters in respiratory apparatus? J Hosp Infect 1997;37(4):263–272.
32. Misset B, Escudier B, Rivara D, Leclercq B, Nitenberg G. Heat and moisture exchanger vs heated humidifier during long-term mechanical ventilation: a prospective randomized study. Chest 1991;100(1): 160–163.
33. Martin C, Perrin G, Gevaudan M, Saux P, Gouin F. Heat and moisture exchangers and vaporizing humidifiers in the intensive care unit. Chest 1990;97(1):144–149.
34. Roustan JP, Kienlen J, Aubas P, Aubas S, du Cailar J. Comparison of hydrophobic heat and moisture exchangers with heated humidifier during prolonged mechanical ventilation. Intensive Care Med 1992; 18(2):97–100.
35. Dreyfuss D, Djedaini K, Gros I, Mier L, Le Bourdelles G, Cohen Y, et al. Mechanical ventilation with heated humidifiers or heat and moisture exchangers: effects on patient colonization and incidence of nosocomial pneumonia. Am J Respir Crit Care Med 1995;151(4): 986–992.
36. Kirton OC, DeHaven B, Morgan J, Morejon O, Civetta J. A prospective, randomized comparison of an in-line heat moisture exchange filter and heated wire humidifiers: rates of ventilator-associated early-onset (community-acquired) or late-onset (hospital-acquired) pneumonia and incidence of endotracheal tube occlusion. Chest 1977;112(4):1055–1059.
37. Kollef MH, Shapiro SD, Boyd V, Silver P, Von Harz B, Trovillion E, Prentice D. A randomized clinical trial comparing an extended-use hygroscopic condenser humidifier with heated-water humidification in mechanically ventilated patients. Chest 1998;113(3):759–767.
38. Thomachot L, Viviand X, Arnaud S, Boisson C, Martin CD. Comparing 2 heat and moisture exchangers, one hydrophobic and one hygroscopic, on humidifying efficacy and the rate of nosocomial pneumonia. Chest 1998;114(5):1383–1389.
39. Thomachot L, Vialet R, Arnaud S, Barberon B, Michel-Nguyen A, Martin C. Do the components of heat and moisture exchanger filters affect their humidifying efficacy and the incidence of nosocomial pneumonia? Crit Care Med 1999;27(5):923–928.
40. Pelosi P, Solca M, Ravagnan I, Tubiolo D, Ferrario L, Gattinoni L. Effects of heat and moisture exchangers on minute ventilation, ventilatory drive, and work of breathing during pressure-support ventilation in acute respiratory failure. Crit Care Med 1996;24(7):1184–1188.
41. Le Bourdelles G, Mier L, Fiquet B, Djedaini K, Saumon G, Coste F, Dreyfuss D. Comparison of the effects of heat and moisture exchangers and heated humidifiers on ventilation and gas exchange during weaning trials from mechanical ventilation. Chest 1996;110(5):1294–1298.
42. Hurni JM, Fiehl F, Lazor R, Leuenberger P, Perret C. Safety of combined heat and moisture exchange filters in long-term mechanical ventilation. Chest 1997;111(3):686–691.
43. Cohen IL, Weinberg PF, Fein IA, Rowinski GS. Endotracheal tube occlusion associated with the use of heat and moisture exchangers in the intensive care unit. Crit Care Med 1988;16(3):277–279.
44. Villafane MC, Cinnella G, Lofaso F, Isabey D, Harf A, Lemaire F, Brochard L. Gradual reduction of endotracheal tube diameter during mechanical ventilation via different humidification devices. Anesthesiology 1996;85(6):1341–1349.
45. Hess DR. And now for the rest of the story (letter). Respir Care 2002;47(6):696–699.
46. Davis K Jr, Evans SL, Campbell RS, Johannigman JA, Luchette FA, Porembka DT, Branson RD. Prolonged use of heat and moisture exchangers does not affect device efficiency or frequency rate of nosocomial pneumonia. Crit Care Med 2000;28(5):1412–1418.
47. Thomachot L, Leone M, Razzouk K, Antonini F, Vialet R, Martin C. Randomized clinical trial of extended use of a hydrophobic condenser humidifier: 1 vs. 7 days. Crit Care Med 2002;30(1):232–237.
48. Djedaini K, Billiard M, Mier L, Le Bourdelles G, Brun P, Markowicz P, et al. Changing heat and moisture exchangers every 48 hours rather than 24 hours does not affect their efficacy and the incidence of nosocomial pneumonia. Am J Respir Crit Care Med 1995;152(5 Pt 1):1562–1569.
49. Daumal F, Colpart E, Manoury B, Mariani M, Daumal M. Changing heat and moisture exchangers every 48 hours does not increase the

incidence of nosocomial pneumonia. Infect Control Hosp Epidemiol 1999;20(5):347–349.
50. Thomachot L, Vialet R, Viguier JM, Sidier B, Roulier P, Martin C. Efficacy of heat and moisture exchangers after changing every 48 hours rather than 24 hours. Crit Care Med 1998;26(3):477–481.
51. Boisson C, Viviand X, Arnaud S, Thomachot L, Miliani Y, Martin C. Changing a hydrophobic heat and moisture exchanger after 48 hours rather than 24 hours: a clinical and microbiological evaluation. Intensive Care Med 1999;25(11):1237–1243.
52. Markowicz P, Ricard JD, Dreyfuss D, Mier L, Brun P, Coste F et al. Safety, efficacy, and cost-effectiveness of mechanical ventilation with humidifying filters changed every 48 hours. a prospective, randomized study. Crit Care Med 2000;28(3):665–671.
53. Boots RJ, Howe S, George N, Harris FM, Faoagali J. Clinical utility of hygroscopic heat and moisture exchangers in intensive care patients. Crit Care Med 1997;25(10):1707–1712.
54. Thomachot L, Boisson C, Arnaud S, Michelet P, Cambon S, Martin C. Changing heat and moisture exchangers after 96 hours rather than after 24 hours: a clinical and microbiological evaluation. Crit Care Med 2000;28(3):714–720.
55. Thomachot L, Viviand X, Boyadjiev I, Vialet R, Martin C. The combination of a heat and moisture exchanger and a Booster: a clinical and bacteriological evaluation over 96 hrs. Intensive Care Med 2002;28(2):147–153.
56. Ricard JD, Le Miere E, Markowicz P, Lasry S, Saumon G, Djedaini K et al. Efficiency and safety of mechanical ventilation with a heat and moisture exhanger changed only once a week. Am J Respir Crit Care Med 2000;161(1):104–109.
57. Thiery G, Boyer A, Pigne E, Salah A, De Lassence A, Dreyfuss D, Ricard JD. Heat and moisture exchangers in mechanically ventilated intensive care unit patients: a plea for an independent assessment of their performance. Crit Care Med 2003;31(3):699–704.
58. Johnson KL, Kearney PA, Johnson SB, Niblett JB, MacMillan NL, McClain RE. Closed versus open endotracheal suctioning: costs and physiologic consequences. Crit Care Med 1994;22(4):658–666.
59. Cereda M, Villa F, Colombo E, Greco G, Nacoti M, Pesenti A. Closed system endotracheal suctioning maintains lung volume during volume-controlled mechanical ventilation. Intensive Care Med 2001;27(4):648–654.
60. Maggiore SM, Lellouche F, Pigeot J, Taille S, Deye N, Durrmeyer X et al. Prevention of endotracheal suctioning-induced alveolar derecruitment in acute lung injury. Am J Respir Crit Care Med 2003;167(9):1215–1224.
61. Cobley M, Atkins M, Jones PL. Environmental contamination during tracheal suction: a comparison of disposable conventional catheters with a multiple-use closed system device. Anaesthesia 1991; 46(11):957–961.
62. Ritz R, Scott LR, Coyle MB, Pierson DJ. Contamination of a multiple-use suction catheter in a closed-circuit system compared to contamination of a disposable, single-use suction catheter. Respir Care 1986;31(11):1086–1091.
63. Freytag CC, Thies FL, Konig W, Welte T. Prolonged application of closed in-line suction catheters increases microbial colonization of the lower respiratory tract and bacterial growth on catheter surface. Infection 2003;31(1):31–37.
64. Heyland DK, Cook DJ, Dodek PM. Prevention of ventilator-associated pneumonia: current practice in Canadian intensive care units. J Crit Care 2002;17(3):161–167.
65. Deppe SA, Kelly JW, Thoi LL, Chudy JH, Longfield RN, Ducey JP et al. Incidence of colonization, nosocomial pneumonia, and mortality in critically ill patients using a Trach Care closed-suction system versus an open-suction system: prospective, randomized study. Crit Care Med 1990;18(12):1389–1393.
66. Combes P, Fauvage B, Oleyer C. Nosocomial pneumonia in mechanically ventilated patients, a prospective randomised evaluation of the Stericath closed suctioning system. Intensive Care Med 2000; 26(7):878–882.
67. Stoller JK, Orens DK, Fatica C, Elliott M, Kester L, Woods J et al. Weekly versus daily changes of in-line suction catheters: impact on rates of ventilator-associated pneumonia and associated costs. Respir Care 2003;48(5):494–499.
68. Kollef MH, Prentice D, Shapiro SD, Fraser VJ, Silver P, Trovillion E et al. Mechanical ventilation with or without daily changes of in-line suction catheters. Am J Respir Crit Care Med 1997;156(2 Pt 1):466–472.
69. Craven DE, Lichtenberg DA, Goularte TA, Make BJ, McCabe WR. Contaminated medication nebulizers in mechanical ventilator circuits: source of bacterial aerosols. Am J Med 1984;77(5):834–838.
70. Weber DJ, Wilson MB, Rutala WA, Thomann CA. Manual ventilation bags as a source for bacterial colonization of intubated patients. Am Rev Respir Dis 1990;142(4):892–894.
71. Woo AH, Yu VL, Goetz A. Potential in-hospital modes of transmission of *Legionella pneumophila*. Demonstration experiments for dissemination by showers, humidifiers, and rinsing of ventilation bag apparatus. Am J Med 1986;80(4):567–573.
72. Kollef MH, Von Harz B, Prentice D, Shapiro SD, Silver P, St John R, Trovillion E. Patient transport from intensive care increases the risk of developing ventilator-associated pneumonia. Chest 1997; 112(3):765–773.
73. Zack JE, Garrison T, Trovillion E, Clinkscale D, Coopersmith CM, Fraser VJ, Kollef MH. Effect of an education program aimed at reducing the occurrence of ventilator-associated pneumonia. Crit Care Med 2002;30(11):2407–2412.