Effect of Ventilator Circuit Changes on Ventilator-Associated Pneumonia: A Systematic Review and Meta-analysis

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BACKGROUND: Recent guidelines concerning prevention of ventilator-associated pneumonia recommend that ventilator circuits should not be changed routinely, but in practice circuit changes at regular intervals persist. METHODS: We searched the MEDLINE, EMBASE, and SCOPUS databases and reviewed citations to identify articles that reported the results of randomized controlled trials and sequential comparison studies that provided a clearly defined intervention of circuit changes (interval ≥ 2 d) and the outcome measure of the development of ventilator-associated pneumonia in mechanically ventilated adult patients. Both authors independently assessed the validity of the included studies, and extracted data using a pre-designed data-collection form. We used a random-effect model to combine data from studies that compared circuit changes every 2 days versus every 7 days, and circuit changes at regular intervals versus no routine circuit change. RESULTS: The search yielded 10 reports, which included 19,169 patients. Compared to patients exposed to circuit changes every 7 days, patients who received circuit changes every 2 days had a higher risk of ventilator-associated pneumonia (odds ratio 1.928, 95% confidence interval 1.080–3.443). Compared to no routine circuit change, changing the ventilator circuit at a 2-day or 7-day interval was associated with an odds ratio of 1.126 (95% confidence interval 0.793–1.599). There was a trend of reduced risk of pneumonia as circuit-change intervals were extended. CONCLUSIONS: Frequent ventilator circuit changes are associated with a high risk of ventilator-associated pneumonia. No routine circuit change is safe and justified. Hospital infection-control policies and bedside practitioners should translate the evidence into clinical practice, if they haven't done so already. *Key words: meta-analysis; respiratory care; pneumonia; prevention; ventilator circuit.* [Respir Care 2010;55(4):467–474. © 2010 Daedalus Enterprises]

Introduction

It has long been suggested that the ventilator circuit poses an important risk of pneumonia in ventilated patients, as evidenced by bacterial colonization of the respiratory tubing.[1] However, circuit colonization originates primarily from the patient's own secretions.[1] It is the contaminated condensates that represent a risk factor for ventilator-associated pneumonia (VAP) because of the possibility of accidental flushing back into the patient's airway during the performance of circuit change procedures.[2] This was confirmed in the study by Craven et al, who demonstrated that changing the ventilator circuit every 24 hours rather than every 48 hours increased the risk of pneumonia (odds ratio [OR] 2.5, 95% confidence interval [CI] 1.3–4.8) by increasing manipulation of the ventilator circuit.[3] Dreyfuss et al subsequently extended the previous study and found that not changing the ventilator circuit had neither adverse effect on circuit colonization nor on the VAP rate, when compared to circuit change every 48 hours.[4] Based on these observations, the Centers for Disease Control and Prevention guideline for prevention of nosocomial pneumonia, published in 1994, recommended that "daily change in ventilator circuits may be extended to ≥48 hours. . . . The maximum time, however, that a circuit can be safely left unchanged on a patient has yet to be determined."[5]

Since then, several studies have investigated the impact on VAP of extending the circuit-change interval beyond 48 hours. Although a few studies showed less VAP associated with extended change intervals,[6,7] the majority of the studies found no significant difference in the VAP rate between more frequent and less frequent circuit changes. The individual studies, however, have been of relatively small size, and their power to detect a significant difference in outcome was low. An earlier meta-analysis that focused on more frequent versus less frequent circuit changes produced a summary estimate that favored infrequent circuit changes.[8] Recent guidelines concerning prevention of VAP recommend that ventilator circuits should not be changed routinely for infection-control purposes, and that change is required only if the circuit becomes soiled or damaged.[8,9] While guidelines reinforce this as accepted practice, circuit changes at regular intervals persist, as demonstrated by a recent multicenter survey in the United States, which found that 55% of intensive care units (ICUs) regularly change the circuits.[10]

In the present study we used an approach of meta-analyses of the existing data, by comparing studies with circuit changes of every 2-days versus 7-days, and comparing studies with circuit changes at regular intervals versus no routine circuit change. If the results are consistent in favoring infrequent circuit changes and/or no routine change, this updated meta-analysis may serve both as a consolidating body of evidence to strengthen guideline recommendations, and perhaps as a trigger for practice change in those hospitals that still change circuits routinely.

Methods

Search Strategy for Identification of Studies

We identified published studies via the MEDLINE, EMBASE, and SCOPUS databases. We searched for papers published in January 1991 through June 2009. The key words for the initial search were *ventilator circuit AND pneumonia*. We then screened potentially relevant abstracts to identify eligible articles for full review. We also performed a hand search of references cited in original and review articles, and in clinical practice guidelines. Finally, we reviewed eligible articles to determine whether they qualified for meta-analysis.

Inclusion Criteria

An article was considered appropriate for meta-analysis if it met the following inclusion criteria:

- Reported the results of a randomized controlled trial, or a sequential comparison study
- Clearly defined interventions of circuit change
- Circuit change interval ≥ 2 days
- Development of VAP was an outcome measure
- Recruited mechanically ventilated adult patients
- Published in a peer-reviewed journal
- Published in English

Data Extraction

Both authors independently read each article that met the inclusion criteria, and performed data extraction using a pre-designed data-collection form. Disagreement and uncertainty were resolved via discussion or by contacting the article's corresponding author. We reached consensus on

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all data. Data extracted from each article included the first author's name, year of publication, clinical setting, study design, patient populations, circuit-change interventions, outcome measure of the development of VAP (events), number of patients, number of events, and other confounding factors (eg, type of circuit and humidifier). If available, we also collected the estimated cost per year associated with circuit changes. The VAP data were recorded as events/patients (%) and events/1,000 ventilator days.

Statistical Analyses

We used OR to compare the risk of VAP in patients who received more frequent circuit changes to the risk in those who received less frequent circuit changes. We calculated pooled ORs with the DerSimonian-Laird random-effects model,[11] which is usually regarded as more appropriate than other statistical approaches when potential heterogeneity is present between studies.[12,13] We performed separate analyses for studies that compared circuit changes every 2 days versus every 7 days, and that compared circuit changes at regular intervals versus no routine circuit change. We calculated the 95% confidence intervals around the ORs. We assessed heterogeneity across studies with the chi-square test and I^2 ($P < .10$, $I^2 > 25\%$). We created forest plots of the individual studies and combined estimates. All analyses were performed with meta-analysis software (MetaAnalyst version beta 2.0, Tufts Medical Center, Boston, Massachusetts).

Results

Characteristics of Included Studies

Ten studies met the inclusion criteria,[4,6,7,14-20] and we used 9 of them in meta-analyses. The studies included 19,169 patients. We excluded one study,[17] because its patients who were receiving mechanical ventilation ≥ 6 h/d were recruited in a subacute facility. In one sequential study,[6] unheated circuits were used in initial 2-day and 7-day change intervals, whereas heated-wire circuits were subsequently introduced with a 30-day change interval. We excluded the 30-day-change interval arm of that study. Five sequential studies[6,7,14,18,19] and one randomized controlled trial[16] compared circuit changes every 2 days to circuit changes every 7 days. The other 3 randomized trials[4,15,20] compared regular circuit changes every 2 days or 7 days to no routine change.

As shown in Table 1, the studies were conducted in the United States and in European and Asian countries, in diverse ICU settings. In all the studies, VAP was diagnosed on clinical criteria,[21] with one exception. In that study[4] invasive lower-respiratory-tract sampling and quantitative cultures were required to establish the VAP diagnosis.[22-24] Table 2 shows the incidence of pneumonia associated with circuit changes.

Circuit Changes Every 2 or 3 Days Versus Every 7 Days

Figure 1 shows a forest plot for 5 sequential studies that compared circuit changes every 2 days to circuit changes every 7 days.[6,7,14,18,19] A meta-analysis that combined these studies produced a summary OR estimate of 1.501 (95% CI 0.952–2.365), with appreciable heterogeneity ($P = .002$, $I^2 = 0.764$). As shown in Figure 1, a trend favoring less frequent circuit changes was observed in all studies except the large study by Lien et al, in Taipei,[19] which enrolled 13,281 ICU and non-ICU patients (see Table 1). The very low pneumonia rate in both groups (around 3%) suggested that the patients in the study had low severity-of-illness scores and/or few risk factors for VAP (see Table 2). Indeed, a meta-analysis without the Taipei study resulted in a summary OR of 1.928 (95% CI 1.080–3.443; heterogeneity: $P = .056$, $I^2 = 0.604$), indicating a pronounced increase of the risk of pneumonia in patients receiving circuit changes every 2 days versus every 7 days (Fig. 2). A meta-analysis that combined these 4 sequential studies[6,7,14,18] with a randomized controlled trial that looked at 2-day, 3-day, and 7-day circuit changes[16] found similar results (OR 1.645, 95% CI 1.080–2.506; heterogeneity: $P = .09$, $I^2 = 0.507$), though the nature of sequential and randomized controlled studies does not allow comparing them in the same analysis.

Circuit Changes at Regular Intervals Versus No Routine Change

Three randomized trials[4,15,20] compared changes every 2 days or 7 days to no routine circuit change. Figure 3 shows a forest plot of OR estimates from these studies. The combined OR estimate was 1.126 (95% CI 0.793–1.599), with no evidence of heterogeneity ($P = .85$, $I^2 = 0.000$).

Risk of Pneumonia With Different Circuit-Change Frequencies

Table 3 shows estimated ORs and 95% CIs associated with different circuit-change frequencies. In the study by Craven and co-workers, which compared circuit changes at 1 day versus 2 days, the OR was 2.5 (95% CI 1.3–4.8).[3] At longer circuit-change intervals the ORs gradually decreased. The OR was 1.928 (95% CI 1.080–3.443) when comparing circuit changes every 2 days or 3 days versus every 7 days, and 1.126 (95% CI 0.793–1.599) when comparing regular changes every 2 days or 7 days to no routine change.

Table 1. Characteristics of Included Studies of Circuit Changes on Ventilator-Associated Pneumonia Among Adult Ventilated Patients

Study	Country	Clinical Setting	Study Design	Duration of Study	Circuit-Change Intervals Studied	VAP Diagnosis	Type of Circuit	Humidifier
Dreyfuss[4]	France	ICU	Randomized	1 y	2 d vs no change	Quantitative cultures	ND	Bubble/wick
Hess[14]	United States	Medical ICU	Sequential	Nov 1992 - Apr 1993	2 d	Clinical criteria	Unheated, disposable	Bubble
		Medical non-ICU wards Surgical ICU Surgical non-ICU wards		Jun 1993 - Nov 1993	7 d			
Kollef[15]	United States	Surgical ICU Trauma ICU Medical ICU Cardiothoracic ICU Neurosurgical ICU	Randomized	Jun 1994 - Dec 1994	7 d vs no change	Clinical criteria	Unheated, disposable	Wick
Long[16]	United States	Medical ICU Neurosciences ICU	Randomized	Oct 1992 - Jun 1993	2 to 3 d vs 7 d	Clinical criteria	Heated-wire, disposable	Wick
Thompson[17]	United States	Ventilator unit of a subacute facility	Sequential	Oct 1994 - Mar 1995	7 d	Clinical criteria	Heated-wire	Wick
				Apr 1995 - Sep 1995	14 d			
Kotilainen[18]	United States	Medical ICU	Sequential	Jan 1993 - Apr 1993	3 d	Clinical criteria	Heated-wire, disposable	ND
		Surgical ICU		May 1993 - Sep 1993	7 d			
Fink[6]	United States	Respiratory ICU	Sequential	Jan 1991 - Dec 1992	2 d	Clinical criteria	Unheated, disposable	Wick
		Medical ICU		Jan 1993 - Dec 1993	7 d			
				Jan 1994 - Dec 1994	30 d		Heated-wire	
Han[7]	China	Respiratory ICU	Sequential	Mar 1998 - Feb 1999	2 d	Clinical criteria	Heated-wire, reusable	Wick
		Surgical ICU		Jun 1999 - Dec 1999	7 d			
		Coronary care unit Non-ICU wards						
Lien[19]	Taiwan	ICU	Sequential	Nov 1991 - Oct 1993	2 d	Clinical criteria	Unheated, reusable	Bubble/wick
		Non-ICU wards		Nov 1995 - Oct 1997	7 d			
Lorente[20]	Spain	Medical-surgical ICU	Randomized	Apr 2001 - Aug 2002	2 d vs no change	Clinical criteria	ND	Heat-and-moisture exchanger

ICU = intensive care unit
VAP = ventilator-associated pneumonia
ND = no data available

Cost Saving Due to Infrequent Circuit Change

Eight studies estimated yearly cost due to circuit changes, based on the cost of material supplies (eg, tubing), sterilization, personnel time, and salaries. As shown in Table 4, substantial cost-savings were obtained from infrequent circuit changes. The estimated yearly cost savings depended on the size of the hospital, number of ventilators in use per

Table 2. Incidence of Pneumonia Associated With Circuit Changes

Study	Study Design	Circuit-Change Interval	Number of Patients	Ventilator-Associated Pneumonia	
				Events/Patients (%)	Events/1,000 Ventilator Days
Dreyfuss[4]	Randomized	2 d	35	31.4	NA
		No change	28	28.6	NA
Hess[14]	Sequential	2 d	1,708	5.6	9.6
		7 d	1,715	4.6	8.6
Kollef[15]	Randomized	7 d	153	28.8	17.4
		No change	147	24.5	16.4
Long[16]	Randomized	2–3 d	213	12.7	9.4
		7 d	234	11.1	9.9
Thompson[17]	Sequential	7 d	31	9.7	1.9
		14 d	18	11.1	1.6
Kotilainen[18]	Sequential	3 d	88	9.1	12.9
		7 d	146	6.2	7.4
Fink[6]	Sequential	2 d	336	10.7	11.9
		7 d	137	2.9	3.3
		30 d	157	6.4	6.3
Han[7]	Sequential	2 d	413	9.2	16.7
		7 d	231	3.5	8.2
Lien[19]	Sequential	2 d	6,213	2.8	2.7
		7 d	7,068	3.2	2.6
Lorente[20]	Randomized	2 d	143	23.1	15.5
		No change	161	23.0	14.8

NA = data not available.

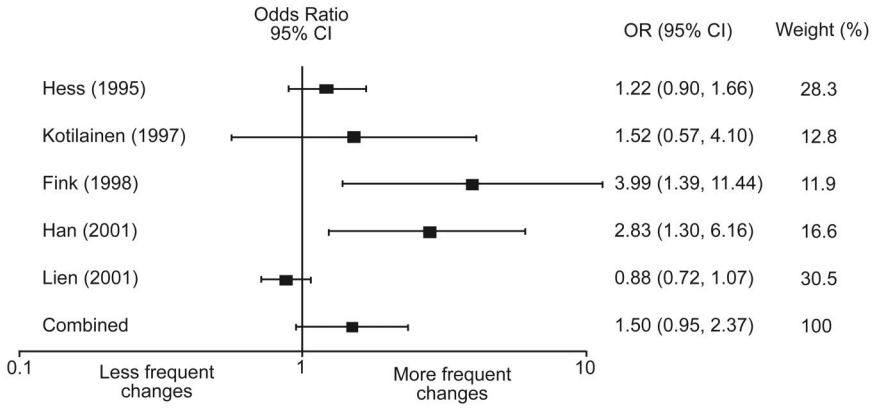

Fig. 1. Forest plot of odds ratios and 95% confidence intervals of ventilator-associated pneumonia with circuit changes every 2 days versus every 7 days, in 5 sequential studies.

day, frequency of circuit changes, and cost of labor and supplies. It ranged from $4,900 in a subacute facility to $111,530 at Massachusetts General Hospital.

Discussion

This updated meta-analysis tracked down 10 published studies on the effect of ventilator circuit change on VAP. The included studies cover a wide range of ICU adult patients from Western developed countries and Eastern developing countries, such as China. The results show that, compared to patients who received circuit changes every 7 days, patients who received circuit changes every 2 days have a higher risk of VAP (OR 1.928, 95% CI 1.080–3.443). Compared to no routine circuit change, periodically changing the ventilator circuits at 2-day or 7-day intervals was associated with an OR of 1.126 (95% CI 0.793–1.599). A trend of reduced risk of pneumonia was

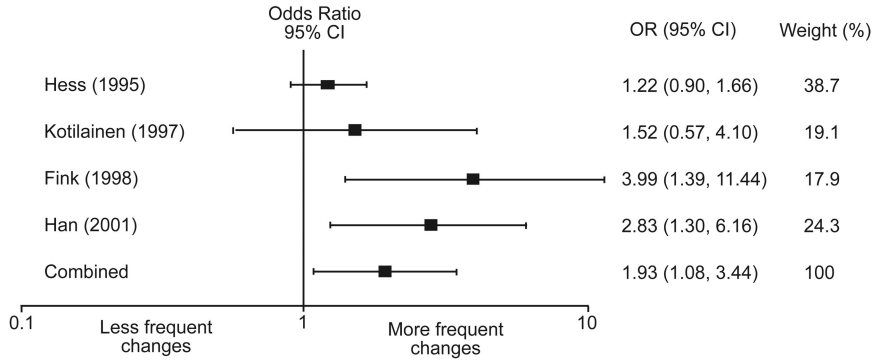

Fig. 2. Meta-analysis similar to Figure 1, except without the study by Lien et al.[19]

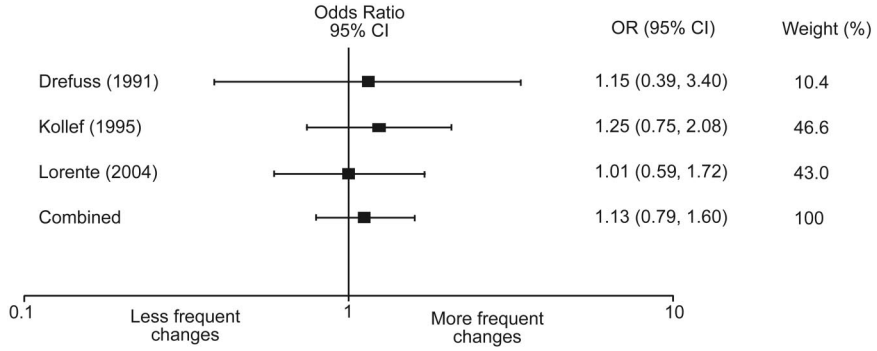

Fig. 3. Meta-analysis of 3 randomized trials on ventilator-associated pneumonia with regular circuit changes every 2 days or every 7 days versus no routine circuit changes.

Table 3. Odds Ratios of Ventilator-Associated Pneumonia With Different Circuit-Change Frequencies

Source	Circuit-Change Intervals Studied	Number of Studies	Estimated Odds Ratio	95% Confidence Interval
Craven[3]	1 d vs 2 d	1	2.5	1.3–4.8
Present study	2 d or 3 d vs 7 d	4	1.9	1.1–3.4
Present study	2 d or 7 d vs no change	3	1.1	0.8–1.6

observed as circuit-change intervals extended. Estimated yearly cost savings from infrequent circuit change depended on the size of the hospital, the number of ventilators in use per day, the frequency of circuit changes, and the costs of labor and supplies. The savings ranged from $4,900 in a subacute facility, up to $111,530 in ICUs of one hospital.

These results yield consistent conclusions that frequent ventilator circuit changes are associated with higher risk of VAP, and no routine circuit change is safe and cost-saving. The question that remains, however, is the maximum duration of time that a circuit can be used safely, as pointed out by a recent clinical practice guideline for VAP prevention.[8] The concern of maximum duration of safe use of a circuit might explain why the practice of routine circuit changes persists,[10,25,26] despite of the consistency of the conclusions.

In the 3 randomized trials that addressed the issue of no routine circuit change, one reported maximum duration of circuit use of 29 days.[4] Although the other 2 trials did not report the maximum duration of use, one recruited patients mechanically ventilated for a mean duration of 15 ± 12 days, and 35% of them were ventilated for > 14 days,[15] another for a mean duration of 20 ± 22 days.[20] Apparently, those trials recruited a large proportion of patients who were undergoing prolonged mechanical ventilation. In contrast to a population-based study in which all mechanically ventilated adult patients in Ontario, Canada, were retrospectively investigated via the administrative database, only 6% of non-cardiac-surgery adult patients were ventilated for ≥ 15 days.[27] Seventy-five percent of the patients were ventilated for 1–4 days, and 19% were ventilated for 5–14 days. The durations of mechanical ventilation in Ontario are remarkably similar to those reported in large United States and international studies.[28,29] From a population point of view, this would mean that about 75% of ventilated patients would use a circuit for only 1–4 days, and another 20% would use a circuit for 5–14 days. Only 5–6% of patients would use a circuit for ≥ 15 days. The meta-analysis on a population of patients

Table 4. Estimated Yearly Cost-Savings Related to Less Frequent Circuit Changes

Study	Setting	Circuit-Change Intervals Studied	Yearly Cost-Savings
Dreyfuss[4]	20 teaching hospitals in Paris	2 d vs no change	$125,000* $210,000†
Hess[14]	Massachusetts General Hospital, Boston	2 d vs 7 d	$111,530
Kollef[15]	Two university hospitals, St Louis, Missouri	7 d vs no change	$18,300‡
Thompson[17]	A subacute facility, Chicago	7 d vs 14 d	$4,900
Kotilainen[18]	A university-affiliated community hospital, Worcester, Massachusetts	3 d vs 7 d	$20,247
Fink[6]	Hines Veterans Affairs Hospital, Hines, Illinois	2 d vs 7 vs 30 d	$18,938 $22,848
Lien[19]	Taipei Veterans General Hospital, Taipei, Taiwan	2 d vs 7 d	$80,000
Lorente[20]	Canary Islands University Hospital, Tenerife	2 d vs no change	$8,200

* Cost-savings with reusable tubes.
† Cost-savings with disposable tubes.
‡ Cost-savings of both hospitals.

on prolonged mechanical ventilation showed that not changing the ventilator circuits routinely is safe.

No routine circuit change does not mean only one circuit per patient. The trials that addressed this issue used a new circuit for each patient and changed the circuit if a mechanical failure or soilage of the circuit tubing was noted.[4,15,20] Obviously, the question is when to change ventilator circuits and when not to change, specifically in patients undergoing prolonged mechanical ventilation, which reminds us of the ancient Chinese Taoist principle of "wu wei," which refers to natural action (ie, knowing when and how to act, and when not to act). Wu wei partly implies a non-interference approach of mindfully observing and acting only at the appropriate time, place, and way, which may be regarded as a fundamental principle in care of ventilator circuits.

Limitations

The primary limitation of the present meta-analysis is with the heterogeneity of the included studies. Most concerning is the different definitions of VAP in the studies, but we do not believe that those differences substantially affect our findings, because the same VAP-diagnosis criteria were used in all the studies. In terms of VAP-prevention practices that may have evolved over the years of data collection, it is possible that infection-control policies were implemented concurrently with (or during) these circuit-change studies that substantially influenced VAP prevalence in sequential studies. However, a meta-analysis specifically of the randomized controlled trials supported the safety of no routine circuit changes.

Summary

Given the evidence, it seems fair to say that it is time to relieve the anxiety regarding the safety of the practice of no routine circuit changes. For infection-prevention purposes, ventilator circuits should not be changed, at least not in adult mechanically ventilated patients, unless the circuit is soiled or damaged. Hospital infection-control policies and bedside practitioners should translate the evidence into clinical practice if they haven't done so already.

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