Extending Ventilator Circuit Change Interval Beyond 2 Days Reduces the Likelihood of Ventilator-Associated Pneumonia*

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Objective: To determine the risk of acquiring ventilator-associated pneumonia (VAP) and the impact on costs when extending ventilator circuit change intervals beyond 2 days to 7 and 30 days. Design: Prospective 4-year review of mechanically ventilated patients. Setting: The respiratory and medical ICUs of an 800-bed tertiary teaching Veterans Affairs hospital. Patients: All adult patients receiving mechanical ventilation from January 1991 through December 1994. Interventions: Ventilator circuits with active heated water humidifiers were changed at 2-day intervals during a 2-year control period, followed by 7-day and 30-day intervals (for 1 year each). Heated wire circuits were adopted with the 30-day interval. The rate of VAP per 1,000 ventilator days was calculated for each circuit change interval group. Survival analysis was used to model VAP with ventilator circuit change to determine risk. Results: During the study period, 637 patients received mechanical ventilation. During the 2 years with 2-day change intervals, the VAP per 1,000 ventilator days was 11.88 (n=343), compared with 3.34 (n=137) and 6.28 (n=157) for 7-day and 30-day change intervals, respectively. The risk of acquiring a VAP for those with a circuit change every 2 days was significantly greater (relative risk, 3.1; p=0.0004; 95% confidence interval, 1.66-5.81) than those with the 7- and 30-day circuit changes. Extending circuit change intervals reduced supply and labor costs averaging $4,231/yr for each ventilator in use. Conclusions: Circuit change intervals of 7 and 30 days have lower risks for VAP than the 2-day intervals, yielding substantial reductions in morbidity as well labor and supply costs.

(CHEST 1998; 113:405-11)

Key words: infection; mechanical ventilation; pneumonia

Abbreviations: CDC=Centers for Disease Control; HME=heat moisture exchanger; MICU=medical ICU; RICU=respiratory ICU; RR=relative risk; VAP=ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) is a common nosocomial infection associated with increased mortality, extended length of critical care, and concomitant increases in hospital costs.1-3 While aspiration of contaminated secretions from the oropharynx and stomach have been identified as a cause, the ventilator circuit, humidifier, and tubing (which connects the patient to the ventilator) also may be involved in the development of VAP.4 Ventilator circuits have been shown to be contaminated with pathogens, often from the patient's secretions, within a few hours of use.5 The impact of pathogens in

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the ventilator circuit on the occurrence of VAP remains unclear. In 1994, revised Centers for Disease Control (CDC) guidelines recommended that the ventilator circuit change interval be no < 48 h, but offered no guidance on how long the change interval may be safely extended. Several groups have reported that extending ventilator circuit change intervals beyond 2 days does not increase the risk of VAP. While a variety of circuit change intervals have been examined, our experience comparing 2-, 7-, and 30-day intervals over a 4-year period within the same institution is unique.

The purpose of this investigation was to determine the risk of acquiring VAP in the critically ill patient when the ventilator circuit change intervals were extended beyond 2 days and to determine the economic impact of these extended circuit change intervals and the addition of heated wire circuits in terms of supply and labor costs.

Materials and Methods

Study Design and Patient Selection

During a 4-year period, all patients receiving mechanical ventilation in both the respiratory ICU (RICU) and the medical ICU (MICU) at Edward Hines Jr. Veterans Affairs (VA) Hospital were concurrently reviewed by an infection control practitioner to identify the presence of VAP using the 1988 CDC criteria. For 2 years, 1991 and 1992, mechanical ventilator circuits were changed at 2-day intervals. On January 1, 1993, a circuit change interval of 7 days was instituted for a 1-year trial period. Based on the data collected, the hospital infection control committee approved permanent adoption of 7-day ventilator circuit change intervals for the institution and approved a limited trial to extend circuit change intervals to 30 days (from January 1994, through December 1994).

Equipment Used

All patients were mechanically ventilated with a microprocessor-controlled ventilator (either a Siemens Servo 900C [Siemens-Elema; Solna, Sweden] or a Puritan Bennett 7200A [Puritan Bennett; Carlsbad, Calif.]), equipped with a wick-type humidifier (Conchatherm; Hudson/RCI; Temecula, Calif). The humidifier was set to deliver temperatures of 33 to 35°C to the patient’s airway using sterile water. From 1991 through 1993, the ventilator circuit consisted of a standard disposable tubing set (Hudson-RCI) with water traps (DHD; Canastota, NY) placed in both the inspiratory and expiratory limbs of the circuit to collect condensate. When substantial condensate formed, these traps were drained a minimum of every 3 h, without breaking the circuit or interrupting mechanical ventilation. In 1994, the ventilator circuit model was changed to incorporate heated wires to reduce the formation of condensate in the ventilator circuit, and thereby eliminate the need for condensation traps. Throughout the entire 4-year period, a closed suction system (Ballard; Draper, Utah) with daily change intervals was utilized with all ventilated patients. Aerosol delivery during mechanical ventilation was accomplished using metered-dose inhalers with a collapsible chamber (AeroVent; Monaghan Medical, Inc; Plattsburgh, NY) placed in the inspiratory limb of the ventilator circuit, which was left in line for the duration of each ventilator circuit use.

Circuit Change Practices

Ventilator circuits (including gas delivery tubing, humidifier reservoir, water reservoir, water traps, aerosol delivery device, and associated adapters) were changed between patients, and at the predetermined circuit change intervals. In addition, ventilator circuits were changed, in part or whole, at the discretion of the respiratory care practitioner when the circuit was visibly soiled or suspected of mechanical malfunction.

Diagnosis of Nosocomial Pneumonia

Patients were concurrently monitored on a daily basis to identify episodes of nosocomial pneumonia during mechanical ventilation and for 48 h after discontinuation of mechanical ventilation (or until death). Patients who required continuation of mechanical ventilation within 48 h of unsuccessful weaning or other discontinuation of mechanical ventilation were kept in the study without interruption.

Identification of VAP was based on the CDC definitions for nosocomial pneumonias, published in 1988, which included the following: (1) rales or dullness to percussion on physical examination of chest and either new onset of purulent sputum or change in sputum, organism isolated from blood culture, and/or isolation of pathogen from transtracheal aspirate, BAL, or bronchoscopy, or biopsy; or (2) chest radiographs showing new or progressive infiltrate, consolidation, cavitation, or pleural effusion, and new onset of purulent sputum or change in sputum, organism isolated from blood culture, isolation of pathogen from transtracheal aspirate, BAL, or bronchoscopy, or biopsy; isolation of virus or viral antigens in respiratory secretions; diagnostic single antibody titer (IgM) or fourfold increase in paired serum (IgG) for pathogen; and/or histopathologic evidence of pneumonia.

A ventilator day was defined as any part of a 24-h calendar day during which a patient received mechanical ventilation. For a pneumonia to be considered ventilator associated, the patient had to receive mechanical ventilation for 24 h or have a witnessed aspiration within the first 24 h of initiation of the ventilator. All successfully weaned patients were monitored for 48 h postmechanical ventilation. Interrater reliability was established by having a single primary reviewer over the 4-year period, with other infection control personnel (three individuals) filling in for short periods such as vacation and holiday coverage. VAP and nosocomial pneumonia data were recorded for patients in both RICU and MICU on standardized forms as a component of the routine infection control surveillance plan for both units. Data on ventilator utilization by patients in both units were collected by the respiratory care service and used to determine the number of patients receiving mechanical ventilation, the number of ventilator days prior to diagnosis of VAP, and the total number of days of mechanical ventilation for each patient.

Costs associated with each circuit change interval were based on actual costs for supplies, adjusted for 1996 dollars, and time standards were established based on American Association for Respiratory Care uniform reporting method, based on our average salary cost of $20/h (including benefits).

Statistical Analysis

Survival analysis was considered appropriate for the censored data, which consists of varying number of ventilator days until the
first occurrence of VAP or termination of ventilation. The data were fit to a Cox proportional hazards model containing the potential predictors ventilator circuit change interval and hospital unit (MICU or RICU). Only those patients with one occurrence of VAP during their ventilator stay were included. Relative risk (RR) was determined for a 2-day interval compared with a 7- or 30-day circuit change interval, when adjusting for unit.

Time to VAP for each interval was determined for individual patients who had only one occurrence of VAP during the hospital stay. The mean number of ventilator days to VAP was calculated and compared between intervals. Percentages of patients who developed VAP within 7 days were calculated. A Kruskal-Wallis test was used to compare ventilator days between intervals for all readmissions and for the individual patients. Rates of VAP per 1,000 days were determined for each interval. All statistical analyses were performed using software (SAS version 6.08; SAS Institute; Cary, NC).

RESULTS

During the 4-year study, 637 patients accounted for 753 cases receiving 7,709 days of mechanical ventilation. Fifty-two unique patients were involved with 60 incidents (9%) that met the definition as having one (or more) VAP during their mechanical ventilation. The control period, consisting of approximately 2 years, resulted in a pneumonia rate of 11.44/1,000 ventilator days for the first year and 12.3/1,000 ventilator days for the second year. During the control period, 17 patients acquired VAP during the first year, and 19 had an occurrence of VAP in the second year (336 individual patients, pneumonia rate of 11.88/1,000). When compared with the control period, there was a decrease in pneumonia rates for the patients in the 7-day circuit change interval and the 30-day circuit change interval (3.34 and 6.28/1,000, respectively) (Table 1). Differences in ventilator days per patient between intervals was not significant (Fig 1).

The mortality of all patients receiving mechanical ventilation and patients with VAP are shown in Figure 1, bottom (C). The mortality rates of ventilated patients averaged (range) 33% (25 to 43%) in the RICU and 40% (32 to 47%) in the MICU. Coincidentally, the rate of mortality in patients with VAP for the same 4-year period was 33% (17 to 50%) in the RICU and 40% (0 to 60%) in the MICU.

The number of ventilator days prior to VAP during the control period was 13.76±9.6 (n=17) the first year, 10.47±8.53 (n=19) the second year, and did not differ significantly between intervals (p=0.869). The numbers of patients who were still receiving mechanical ventilation at time intervals of 2, 7, 14, 21, and 30 days after initiation were similar between years.

When including all circuit changes in a Cox pro-

<table>
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<th>Table 1—Comparison*</th>
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<td>Interval, d</td>
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</tr>
<tr>
<td>7</td>
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<tr>
<td>30</td>
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*Comparison of number of patients ventilated, VAP rate per 1,000 days of ventilation, the number of ventilator days to VAP±SD, the number of patients (n), and the percent of VAPs that occurred in the first 7 days of ventilation between each change interval for all unique patients during their first admission to the RICU or MICU requiring mechanical ventilation over the 4-year study period (used in the survival analysis).
portional hazards model, the risk of occurrence of VAP was less for both the 30-day (RR=0.407, p=0.013) and 7-day (RR=0.210, p=0.003) circuit change intervals compared with the 2-day interval group. The difference in occurrence of VAP between 7- and 30-day intervals was not significant (p=0.266). RRs were also determined for a model containing a combined 7- and 30-day interval (Table 2) showing a significantly greater risk of acquiring VAP on a 2-day circuit change interval as well as a greater risk for patients who resided in the MICU than those treated in the RICU.

Cost Analysis

Figure 2 shows the accumulated supply and labor costs associated with circuit changes for each patient requiring mechanical ventilation for >2, 7, 14, 21, and 30 days for each change interval studied. Changing from a 2-day (averaging $23,460/yr) to 7-day interval ($4,522/yr) represented an 80% reduction in costs, while extending to 30-day intervals ($612/yr) yielded an additional 7% savings. With an average of 5.4 ventilators in use each day over the 4-year period, cost reductions from 2- to 30-day intervals averaged $4,231 per ventilator per year.

Discussion

We found that extending ventilator circuit change intervals beyond 2 days resulted in significant reductions in both the rate and risk of VAP when compared with 2-day circuit change intervals. The difference in occurrence of VAP between 7- and 30-day intervals was not significant, while the difference in RR identified in our MICU compared with the RICU was most likely related to admission criteria for more acutely ill patients with multisystem failure in that unit. Both RICU and MICU are managed by the pulmonary/critical care team, providing consistency in management strategies such as the use of antibiotics, antacids, mechanical ventilation, and infection control surveillance strategies in the two critical care units over the 4-year period. Our study has the unique advantage of a 2-year control period, followed by 12 months of experience with each change interval period studied.

Our study was limited by the inability to blind observers identifying VAP, the lack of a concurrent control group, and the comparison of other potential risk factors of VAP. The fact that we did not have access to APACHE (acute physiology and chronic health evaluation) scoring for the two units for the entire 4-year period and did not track concurrent use of pre-VAP antibiotic and antacid therapy meant that these variables were not included in the risk analysis.

Our VAP data, which were identified prospectively based on the largely clinical criteria from the CDC,15 serve as the standard for identifying and comparing VAP rates in the United States. While clinical criteria to establish the diagnosis of VAP might not be as accurate as lower respiratory tract sampling methods, recent reports by Timsit and colleagues19 suggest that both clinical and invasive diagnostic methods are associated with similar outcomes for patients suspected of having VAP. Although characterizing causative pathogens may have been more accurately accomplished with more uniform use of protected specimen brushings with quantitative cultures, the etiology and subsequent treatment of VAP was beyond the scope of this investigation. While a randomized design would have substantially increased the credibility of our findings, once we had experienced such substantial reductions in VAP, we were reluctant to subject patients to the apparent increased risk, and the institution to the increased costs, associated with 2-day change intervals.

This reduction in VAP with extended ventilator circuit change interval was not associated with an overall decrease in ventilator days or a decrease in mortality in either ICU. Similar findings were reported by Papazian and colleagues30 who reported that diagnosis of VAP did not correlate with increased mortality in the ICU.

Table 3 summarizes previously published studies of extended ventilator circuit change intervals beyond 2 days, specifying the type of humidifier and ventilator circuit, dates of the study (unless randomized), change intervals studied, number of patients, total ventilator days, and VAP per 1,000 ventilator days.

Our results support the findings of other investigators that extending circuit change intervals from 2 to 7 days reduces the rate and risk of pneumonia.9,10,15 While the interval change from 7 to 30 days did not significantly increase the risk or rate of pneumonia, the trend toward an increase in VAP per

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>Significance</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit change (2 d)</td>
<td>1.134</td>
<td>0.319</td>
<td>0.0004</td>
<td>3.108 (1.662, 5.812)</td>
<td></td>
</tr>
<tr>
<td>Unit (MICU)</td>
<td>1.015</td>
<td>0.300</td>
<td>0.0007</td>
<td>2.760 (1.534, 4.966)</td>
<td></td>
</tr>
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*The results of the Cox proportional hazards survival model for the censored data consisting of number of ventilator days until the first occurrence of VAP or termination of ventilation. Results are expressed as coefficient, SE, significance, RR and 95% confidence interval (CI). Variables shown are 2-day circuit change interval compared with combined 7- and 30-day data, and MICU compared to the RICU.
1,000 ventilator days suggests that somewhere between 7 and 30 days may exist an optimal circuit change interval. The rate of VAP with 30-day intervals in the 2 years subsequent to the study period has trended back to the levels seen with the 7-day intervals lending support to the statistical analysis that the difference between 7 and 30 days was not clinically significant. Based on these observations, we believe that extending the interval from 2 to 30 days has reduced the rate and risk of VAP.

Craven and coworkers,\textsuperscript{6} in 1986, were the first (to our knowledge) to demonstrate actual reductions in risk of VAP with extended circuit change intervals. In a study of risk factors for nosocomial pneumonia in 233 critically ill patients requiring mechanical ventilation, a logistic regression analysis identified a two-fold increase in risk of VAP, with 24-h circuit change intervals when compared with 48 h. They theorized that the increased rate of pneumonia resulted from increased manipulation of the patient, endotracheal tube, or ventilator tubing, which may result in inadvertently flushing contaminated tubing condensate into the patient or increase leakage of bacteria around the endotracheal tube into the trachea.\textsuperscript{6}

![Graph showing supply and labor costs associated with ventilator circuit changes for each year based on the number of circuit changes required and the duration of ventilation of patients for each circuit change interval and year studied.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21759/)

**Figure 2.** Supply and labor costs associated with ventilator circuit changes for each year based on the number of circuit changes required and the duration of ventilation of patients are shown for each circuit change interval and year studied.

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**Table 3—Comparison of Reports of Extended Ventilator Circuit Change Intervals**

<table>
<thead>
<tr>
<th>First Author, yr</th>
<th>Humidifier</th>
<th>Circuit</th>
<th>Dates</th>
<th>Change Interval Days</th>
<th>No. of Patients</th>
<th>Ventilator Days</th>
<th>VAP/1,000 Ventilator Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boher,\textsuperscript{9} 1991</td>
<td>Wick</td>
<td>Standard</td>
<td>7/90-6/91, 7/91-12/91</td>
<td>2, 7</td>
<td>1,172, 518</td>
<td>18, 13</td>
<td></td>
</tr>
<tr>
<td>Alfredson,\textsuperscript{10} 1994</td>
<td>Wick</td>
<td>Standard</td>
<td>8/92-2/93</td>
<td>2-3</td>
<td>2,958, 2,500</td>
<td>13,46, 12,356</td>
<td>11.9, 4.8</td>
</tr>
<tr>
<td>Hess,\textsuperscript{13} 1995</td>
<td>Bubble</td>
<td>Standard</td>
<td>11/92-4/93, 6/93-11/93</td>
<td>2, 7</td>
<td>1,708, 1,715</td>
<td>9,858, 9,160</td>
<td>9.6, 8.6</td>
</tr>
<tr>
<td>Dreyfuss,\textsuperscript{11} 1991</td>
<td>Wick/bubble</td>
<td>Standard</td>
<td>1 year, Randomized</td>
<td>2, 7</td>
<td>448, 875</td>
<td>24, 17.4</td>
<td></td>
</tr>
<tr>
<td>Dreyfuss,\textsuperscript{14} 1995</td>
<td>Wick/bubble</td>
<td>Standard</td>
<td>17 months, Randomized</td>
<td>No change, No change</td>
<td>28, 61</td>
<td>280, 610</td>
<td>28.6, 10.2</td>
</tr>
<tr>
<td>Kollef,\textsuperscript{12} 1995</td>
<td>Wick</td>
<td>Standard</td>
<td>1 year, Randomized</td>
<td>No change, No change</td>
<td>70, 147</td>
<td>875, 2,190</td>
<td>9.14, 16.4</td>
</tr>
<tr>
<td>Present study</td>
<td>Wick</td>
<td>Standard</td>
<td>1/91-12/92, 1/93-12/93</td>
<td>2, 7</td>
<td>403, 164</td>
<td>4,030, 1,553</td>
<td>11.3, 3.2</td>
</tr>
<tr>
<td></td>
<td>Heated wire</td>
<td></td>
<td>1/94-12/94</td>
<td>30</td>
<td>181</td>
<td>2,172</td>
<td>6.6</td>
</tr>
</tbody>
</table>
The reduction of manual resuscitation bag ventilation with fewer circuit changes and with the use of closed-suction catheters may be a factor in our findings of reduced VAP. As the manual resuscitator is attached to the airway during circuit changes, leakage may occur around the cuff allowing bacteria to enter the airway, while relatively high inspiratory flow patterns at the end of the airway might result in creating a crude nebulizer, shearing bacteria from the tip of the airway into respirable particles. These particles would reach the lung parenchyma more effectively than bacteria casually aspirated. We did not find further reduction in VAP with elimination of condensate through use of heated wire circuits.

Craven et al also identified a twofold increase in risk of pneumonia during the fall and winter seasons. It is of interest to note that of the nonrandomized studies comparing 2- to 7-day change intervals, those that compared the same months in different years reported significant decreases in VAP rates. Both Boher and Alfredson (personal communication; Terry L. Alfredson, MBA, RRT; November 12, 1997) noted consistent reductions in VAP in most critical care units when comparing the different change intervals within the same months. Hess et al, comparing two consecutive time periods, reported only a slight decrease in rate and risk of VAP with 7-day change intervals.

Two-Day Changes vs No Changes

Our findings also agree with findings of studies comparing 2- or 7-day circuit change intervals with no routine changes. With only 54 of 748 patients (7.2%) receiving mechanical ventilation for >30 days, we might reasonably consider our 30-day change intervals to be similar to no routine changes. In a randomized study, Dreyfuss et al reported no difference in the occurrence of VAP when comparing 2-day circuit change intervals with no changes using heated humidification. In a subsequent study, with a larger patient population, the use of heated humidification with heat moisture exchangers (HMEs) was compared with no routine circuit changes. No difference between the groups was found, but there was a much lower rate of VAP than in the previous study.

Seven-Day Changes vs No Changes

Kollef et al compared 7-day circuit change intervals with no changes during mechanical ventilation, and found no significant differences in risk of VAP or mortality between the two groups, although a subgroup analysis of patients with a tracheotomy showed a greater risk of VAP with more frequent circuit changes. Similarly, we found that the difference in rate and risk of VAP between 7- and 30-day circuit change intervals was not significant.

None of the studies to date have identified a greater risk of VAP when extending circuit change intervals beyond 2 days, and extending intervals from 2 to 7 days resulted in greater reductions in rate and risk of VAP (in three of four reports) than other intervals studied. Costs notwithstanding, these data suggest that ventilator circuit change intervals should at least be 7 days, with 30 days or no routine change presenting no significant additional risk.

Implication of Heated vs Unheated Circuits

Initiating heated wire circuits while extending circuit change intervals from 7 to 30 days is a confounding variable for our study. We began using heated wire circuits to reduce the supply costs of sterile water used in the humidifier and to reduce the labor costs associated with removal and proper disposal of the potentially contaminated condensate from the ventilator circuit. Condensate that rains out in the ventilator circuit has been shown to be readily contaminated, primarily with pathogens from the patient, and identified as a risk factor for VAP. With standard ventilator circuits, active humidifiers heat and humidify gas to 50°C with 80 mg of H2O/L in order to deliver 33°C containing 40 mg of H2O/L to the patient’s airway. The 40 mg of H2O/L leaving the humidifier that does not reach the patient’s airway forms condensate in the ventilator circuit that is readily contaminated by pathogens from the patient. Heated wire circuits maintain the temperature of the gas en route from the humidifier to the patient eliminating the formation of condensate, reducing the utilization of water by 50%. Heated wire circuits reduce the risk of lavage of the patient’s airway with contaminated condensate and eliminates the need to remove water from the circuit. Despite the elimination of this risk factor, there was no difference in VAP with the use of heated wire circuits. In fact, our highest (2-day interval) and lowest (7-day interval) VAP rates were found using standard nonheated circuits. Alfredson and coworkers experienced similar changes in VAP rates with 7-day intervals changing from a standard to heated wire circuit, leading us to believe that our adoption of heated wires probably was not a major factor in maintaining reduced risks.

The substitution of HMEs for active heated humidifiers has been advocated to decrease the risk of VAP by filtering out contaminated aerosols and eliminating development of condensate in the ventilator circuit. Dreyfuss and coworkers compared the use of heated humidifiers (with heavy contamination of condensate in an unchanged circuit) and the use of condensate-free HMEs (with a bacterial
filter capability of >99%) and found no difference in patient microbial colonization of lung secretions or incidence of VAP.

Based on our actual costs with heated wire circuits in 1994, calculated costs for circuit changes averaged $114 per patient (2 day), $27.60 per patient (7 day), and $3.38 per patient (30 day). With an estimated 550,000 adults receiving mechanical ventilation >7 days in the United States in 1993 (Warren Sanborn, PhD; personal communication; 1993), extending circuit change intervals from 2 to 7 days would save $47,520,000 in supplies and labor, while extending change intervals to 30 days would save an additional $11,660,000. Wholesale adoption of 30-day circuit change intervals could result in nationwide savings of $59,180,000 of needless costs annually.

In summary, to our knowledge, no studies have identified a greater risk of VAP when extending circuit change intervals beyond 2 days. Our findings suggest that extending ventilator circuit change intervals, with or without heated wire circuits, to 7 and 30 days results in reductions of VAPs per 1,000 ventilator days, risk of VAP, and costs for supplies and labor of mechanical ventilation averaging $4,231 per ventilator per year.

We conclude that extending ventilator circuit change interval from 2 days to an interval of 7 and 30 days reduced risk of VAP as well as labor and supply costs associated with circuit changes in mechanically ventilated patients.

ACKNOWLEDGMENT: The authors thank Mose Fisher, RRT, and Lynnle Hodge for their help with data collection.

REFERENCES