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Arzu Ari

Georgia State University, aari1@gsu.edu

James B. Fink

Georgia State University, jfink@gsu.edu

Susan P. Pilbeam

Baptist Medical Center, Jacksonville, Florida

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Secondhand aerosol exposure during mechanical ventilation with and without expiratory filters: An in-vitro study

Arzu Ari, James B Fink, Sue Pilbeam

Email: arzuari@hotmail.com

Abstract

Background: Concerns have been expressed about risk of exposure to exhaled aerosols to ICU personnel. **AIM:** To quantify amount of aerosol collected at the exhaust outlet of mechanical ventilators operated with and without filters in the expiratory limb. **Methods:** Two categories of ventilators were tested: (1) Ventilators without Proprietary Filters: Servo-i (Maquet) and Galileo (Hamilton) and (2) Ventilator with proprietary filters: PB 840 (Covidien). Each ventilator was attached to a simple test lung and operated with VT 500 ml, RR 20 bpm, PIF 50 L/min, PEEP 5 cmH₂O. Four separate doses of albuterol (2.5 mg/3mL) were administered via jet nebuliser (eValueMed, Tri-anim) placed at the “Y”. In Experiment A, a filter (Respirgard 303) was placed at the exhaust port. In Experiment B, two filters were attached to the ventilators without proprietary filters: (1) at the end of expiratory limb and (2) at the exhaust outlet. Drug was eluted from filters and measured using spectrophotometry. **Results:** Drug deposited at the exhaust port without expiratory filtering was >160 fold higher than with expiratory filtering. The collecting filter used in this study was less efficient than the proprietary filter designed for use with the ventilator. Regardless of type of filter used, placement of filter in the expiratory limb reduced secondhand aerosol exposure significantly. **Conclusion:** Risk of secondhand exposure to exhaled aerosol can account for >45% of nominal dose as well as droplet nuclei produced by patients. Using expiratory filters decreases risk of exposure to aerosol released to the atmosphere during mechanical ventilation.

Keywords: Aerosols, mechanical ventilation, secondhand aerosol exposure, and inhalation therapy.

Introduction

While many studies have quantified delivery of medical aerosols to the lungs of mechanically ventilated patients, less is known about the fate of aerosols which are exhaled by the patient and those aerosols which bypass the patient completely. Both types of aerosol entering the ambient environment may result in ‘secondhand exposure’ and provide cause

for concern. Second hand exposure to medication intended for inhalation may have deleterious impact on care providers, visitors and other patients in the vicinity. For example, secondhand exposure to inhaled bronchodilators by health care professionals has been associated with development of occupational asthma.¹⁻¹⁴ Respiratory therapists have an increased risk of developing asthma after entering the profession.^{15,16} That may be explained in part by their work environment as they are responsible for patient care with inhaled medications, routine monitoring of patients, equipment cleaning and maintenance that may cause exposure to a range of aerosolised substances in the hospital setting. Some studies show that there is an economic impact of respiratory-related work disability due to work loss and reported that better control of workplace

Arzu Ari, PhD, RRT, PT, CPFT, FAARC
Associate Professor, Georgia State University, Division of Respiratory Therapy, Atlanta

James B Fink, PhD, RRT, FAARC, FCCP
Adjunct Professor, Georgia State University, Division of Respiratory Therapy, Atlanta

Sue Pilbeam, MS, RRT, FAARC
Respiratory Therapist, Baptist Medical Center, Jacksonville, FL
Respiratory Care Consultant, 9 Althea Street, Saint Augustine, FL 32084

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exposure may reduce work disability caused by respiratory conditions.^{12,17-19}

We know that patients while coughing, talking and even laughing can generate aerosols as droplet nuclei capable of transmitting bacteria and viral vectors. Exhaled particles from intubated patients are likely to have mass median aerodynamic diameters (MMAD) of less than 2 μm , as no particles of a greater diameter than that have been observed exiting endotracheal tubes. Particles in this range tend to not deposit *via* inertial impaction or sedimentation, and are capable of remaining suspended in the air for extended periods of time. For infectious agents, where low concentration exposure is sufficient for transmission, exhaled patient generated aerosols may pose the most ominous risks. Exhaled particles from patients with pulmonary tuberculosis (TB) have been documented to infect other patients between wards and separate health care facilities.^{20,21} Similarly, severe acute respiratory syndrome (SARS) and influenza A virus subtype H1N1 has been shown to be transmitted by droplet nuclei generated by patients. Environmental exposure to antibacterial agents may also contribute to the development of resistant organisms and hence increase the risk of airborne infection.²²⁻²⁵ Due to the proximity of acutely ill patients within the hospital, it is reasonable to assume that pathogenic bacteria exist in higher concentrations in the hospital environment than in the home. When aerosols containing antibiotics settle on surfaces in the patient room and vicinity, they may expose the ambient bacteria to concentrations that are well below the level required to kill the bacteria. Low concentration exposure to antibiotics is associated with the development of species that are resistant to that antibiotic.²⁶

To the best of our knowledge, none have described secondhand aerosol exposure during mechanical ventilation although aerosols are commonly administered to ventilator-dependent patients. Commercial mechanical ventilators vary in their approach to providing or recommending use of filters in the expiratory limb of the ventilator circuit. In many cases, such filters are required to reduce the volume of drug depositing on sensors and/or valves distal to the exhalation limb of the

ventilator circuit. Some ventilators are designed to require the use of proprietary filters, while others do not, but recommend their use.

For this paper the term proprietary filter is defined as any filter required for use with a specific ventilator, which cannot be readily substituted with any other filter. They are typically larger, more complex high-efficiency particulate air (HEPA) filters than other simpler, low volume expiratory filters that may be placed in the circuit. Despite its importance, there have been no studies showing the effect of using expiratory or proprietary filters on ventilator-dependent patients on secondhand aerosol exposure during mechanical ventilation. Therefore, the objective of this study was to quantify the amount of aerosol that exits from the ventilator exhaust port under a variety of conditions ranging from no filter, to the use of a filter placed in the circuit, to the more sophisticated proprietary filters integral to the ventilator.

Methods

Filtration and Ventilators: The types of filtration that were tested with ventilators in this study were divided into two categories: 1) Ventilators without filters in the expiratory limb: The Servo-i (Maquet Inc, Wayne, NJ) and the Galileo (Hamilton Medical, Reno, NV), and (2) A ventilator with a proprietary filter in the expiratory limb: PB 840 (Covidien-Nellcor™ and Puritan Bennett™, Boulder, CO). Each ventilator was attached to a passive test lung and operated in volume control ventilation with adult parameters (V_T 500 ml, RR 20 breaths/min, PIF 50 L/min, and PEEP 5 cmH_2O).

Experiments: As shown in Figure 1, in all experiments, a collecting filter was placed distal to the ventilator expiratory exhaust port. In Experiment A, there was no filter at the end of the expiratory limb with the aim of determining secondhand aerosol exposure during mechanical ventilation without expiratory filtration. In Experiment B, a filter (Respigard II, Vital Signs, Englewood, Colorado) was placed in the expiratory limb proximal to the ventilator to determine the effect of using a filter at the end of the expiratory limb on secondhand aerosol exposure during mechanical ventilation.

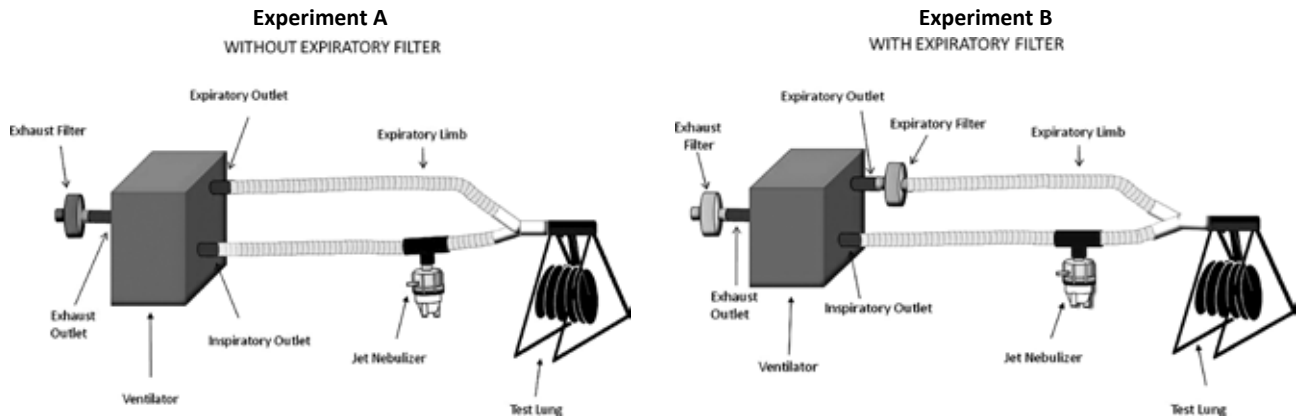


Figure 1: Illustrations of the experimental set-ups used in Experiment A and Experiment B

Data collection: For each experiment, albuterol (2.5 mg/3mL) was nebulised *via* a jet nebuliser (eValueMed, Tri-anim) placed in the inspiratory limb at the “Y” adaptor (n=3). The nebuliser was operated continuously with 100% oxygen at 8 L/min using a back pressure compensated flow meter (Timemeter, St. Louis, MO). Nebulisation continued until 1 minute past initiation of sputter. Drug was eluted from the filters with 5 mL of 0.1 N HCl, with agitation for 1 minute. Quantity of eluted drug was determined by a UV spectrophotometer (Beckman Coulter) at 276 nm.

Data analysis: The Statistical Package for Social Science version 18 (SPSS Inc, Chicago, IL) was used for the data analysis of this study. Using descriptive statistics, secondhand aerosol exposure was expressed as a mean (\pm SD) percentage of the nominal dose placed in nebuliser. Independent sample t-test and one way analysis of variance (ANOVA) were conducted to compare the amount of aerosol exiting from the exhaust port of each ventilator. A p-value of less than 0.05 was considered to be statistically significant.

Results

Table 1 shows the percent of nominal dose (mean \pm standard deviation) delivered to the atmosphere

through the ventilators with or without expiratory and proprietary filters.

Secondhand aerosol exposure without expiratory and proprietary filters: The findings of this study showed that drug deposited at the exhaust port of the ventilator without expiratory and proprietary filter ranged from 40% to 45% (Table 1).

The effect of proprietary filters on secondhand aerosol exposure during mechanical ventilation: In Experiment A, comparisons of drug deposited at the exhaust filter revealed significant differences between ventilators with and without proprietary filters (p=0.0001). Drug deposited at the exhaust port with proprietary filters was 0.25% in PB 840, which was 160 fold less than the ventilators without proprietary filters. It was found that use of proprietary filters with ventilators was the most efficient way of preventing secondhand aerosol exposure.

The effect of expiratory filters on secondhand aerosol exposure during mechanical ventilation: After the placement of expiratory filters on Servo-I and Hamilton Galileo in Experiment B, comparisons of drug deposition at the exhaust and expiratory filters were repeated and a significant difference on

Table 1: Percent of nominal dose (mean \pm standard deviation) delivered to the atmosphere through the ventilators with or without expiratory and proprietary filters.

Ventilators without Proprietary Filters						Ventilators with Proprietary Filters
Servo-i			Hamilton Galileo			PB 840
Experiment A	Experiment B		Experiment A	Experiment B		Experiment A
Exhaust Filter only	Expiratory Filter	Exhaust Filter	Exhaust Filter only	Expiratory Filter	Exhaust Filter	Exhaust Filter only
40.6 \pm 0.21%	39.9 \pm 10.4%	2.2 \pm 1.2%	45.1 \pm 5.1%	54.6 \pm 5.3%	6.1 \pm 0.7%	0.25 \pm 0.1%

the exhaust filter ($p=0.007$) was found, while there was no significant difference between drug deposited on the expiratory filters of the Servo-i and the Hamilton Galileo ($p=0.09$). As shown in Table 1, placement of expiratory filters on the expiratory limb of the ventilator circuit reduced secondhand aerosol exposure during mechanical ventilation by 94% in Servo-i and 88% in Hamilton Galileo ventilators. Placement of a collecting filter at the end of the expiratory limb decreased secondhand aerosol exposure significantly both in Servo-i and Hamilton Galileo ($p=0.0001$ and $p=0.004$, respectively).

Discussion

The intent of our study was to quantify the amount of aerosol that is released into the environment from administration of bronchodilators through a mechanical ventilator, and to determine the impact of various forms of expiratory filtration. We found that the amount of inhaled bronchodilator exiting the ventilator ranged from 0.25% to 45% of a nominal dose placed in the nebuliser depending on the type of filters used during mechanical ventilation.

A standard small volume nebuliser operating continuously during administration of bronchodilators in an ambulatory setting typically has 0.8 – 1.2 mL of medication remaining in the reservoir at the end of nebulisation. With a 3 mL dose placed in the nebuliser, approximately 50 to 66% of the nominal drug is emitted from the nebuliser as aerosol. Consequently, the 45% of dose we measured exiting the exhaust port of the ventilator represents 68–90% of all aerosol entering the ventilator circuit, identifying the ventilator as a rather efficient vehicle for aerosol transmission into the atmosphere. Our findings suggest that any aerosol emitted into the ventilator circuit, whether from the nebuliser or the patient's airway might be expected to pass through the ventilator circuit and exhaust port with similar efficiency. At the time of this study, there were no data identified in the literature investigating secondhand aerosol exposure during mechanical ventilation. Therefore, no comparison could be made to the data collected in this study.

However, it is very well known that respiratory therapists frequently administer aerosolised

medications, with continuous small volume nebulisers which may spew 2/3s of the emitted aerosol into the atmosphere. When a portion of the aerosolised medication enters the atmosphere, it exposes those individuals in the vicinity to inhalation of these same medications along with the potential inhalation of aerosolised organisms from the patients' airways and lungs.²⁷ Those who inhaled aerosol particles might be at risk of exposure for unwanted side effects. To verify that health care workers do, in fact, inhale portions of the medication exhaust, Carnathan *et al* reported that respiratory therapists have traces of inhaled medication in their plasma when exposed to aerosolised racemic S & R isomers of albuterol.¹⁶ In a study by Shults *et al*, nurses and respiratory therapists were found to have ribavirin in their urine when they were exposed to patients receiving ribavirin treatments.²⁸ Although none of these studies have been conducted on health-care professionals taking care of ventilator-dependent patients, they all show that secondhand aerosol exposure and uptake may result in some side effects on individuals inhaling aerosolised medications.

According to the findings of this study, using expiratory filters during mechanical ventilation decreases the risk of exposure to aerosol released to atmosphere from the ventilator. The proprietary filter tested was the most efficient option, with only 0.25% of dose escaping the exhaust port. The other filter options allowed 8 – 24 fold more aerosols to pass through the exhaust into the ambient environment. This difference could prove to be a critical difference with transmission of infectious droplet nuclei entering into the ICU or any acute care facility. The case could be made that the higher level of filtration efficiency should be considered the safer standard than use of the less complex filters.

Another aspect of filter design is the amount of time that a filter can efficiently remove aerosols from gas prior to increasing resistance to flow of that gas. The greater the surface area of the filtration elements the longer they can collect material prior to increase in resistance. Simple filters have less internal area and may have increased resistance in a shorter period. The difference in time to increased resistance may range from hours to days. Changes in expiratory resistance in the ventilator circuit can

impact pressures and work of breathing. Filters should be selected which have the least impact in terms of both time of use before resistance changes, and the degree of resistance changes that occur. Evaluation of these parameters is beyond the limits of this study. Therefore, future research on a broad scale is needed in order to understand clinical and environmental effects of second-hand aerosol exposure during mechanical ventilation.

In conclusion, respiratory therapists, nurses, health care workers, patients and families are exposed to a variety of infectious agents and aerosolised medications in the health care environment. As long as second-hand aerosol exposure continues to be a problem, health care professionals should be able to protect themselves from possible side effects of second-hand aerosol exposure while caring for patient's respiratory needs. The results of our finding suggest that aerosol generated during mechanical ventilation can readily be transmitted to the ambient environment, and that simple measures such as use of filters in the expiratory limb can greatly reduce risk of second-hand aerosol exposure.

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