


Evaluating cross contamination on a shared ventilator

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ABSTRACT

Background Disasters have the potential to cause critical shortages of life-saving equipment. It has been postulated that during patient surge, multiple individuals could be maintained on a single ventilator. This was supported by a previous trial that showed one ventilator could support four sheep. The goal of our study is to investigate if cross contamination of pathological agents occurs between individuals on a shared ventilator with strategically placed antimicrobial filters.

Methods A multipatient ventilator circuit was assembled using four sterile, parallel standard tubing circuits attached to four 2 L anaesthesia bags, each representing a simulated patient. Each 'patient' was attached to a Heat and Moisture Exchange filter. An additional bacterial/viral filter was attached to each expiratory limb. 'Patient-Lung' number 1 was inoculated with an isolate of *Serratia marcescens*, and the circuit was run for 24 hours. Each 'lung' and three points in the expiratory limb tubing were washed with broth and cultured. All cultures were incubated for 48 hours with subcultures performed at 24 hours.

Results Washed cultures of patient 2, 3 and 4 failed to demonstrate growth of *S. marcescens*. Cultures of the distal expiratory tubing, expiratory limb connector and expiratory limb prefilter tubing yielded no growth of *S. marcescens* at 24 or 48 hours.

Conclusion Based on this circuit configuration, it is plausible to maintain four individuals on a single ventilator for 24 hours without fear of cross contamination.

INTRODUCTION

Disasters (man-made or natural) have the potential to overwhelm healthcare systems and cause critical deficits of life-saving equipment. In such shortages, it has been postulated that multiple individuals could be connected in parallel to a single ventilator.¹ While this has not been studied on humans, a previous study by Paladino *et al*² demonstrated that it was feasible to ventilate four adult-sized sheep with normal lung compliance on a single ventilator for 12 hours. A blog post reports multiple individuals survived on one ventilator during the 2017 Las Vegas shooting, but no data were captured at that time from that event.³

Concerns regarding the ventilation of multiple individuals on a single ventilator include difficulty managing volumes and pressures, difficulty measuring individual patient ventilator parameters, the potential for accidental extubation, of one patient by another, and the potential cross contamination of infectious pathogens.

Key messages

What is already known about this subject

▶ Prior feasibility studies have shown that during disaster scenarios, it is possible to maintain more than one individual on a shared ventilator. Unfortunately, the safety regarding the spread of infectious respiratory pathogens is yet to be assessed.

What this study adds

▶ This in vitro study studied cross contamination among four latex-free anaesthesia bags ('lungs') on separate circuits connected to a single ventilator. There was no evidence that the single 'infected' lung caused infection of the other three sharing the ventilator, suggesting that droplet sized respiratory pathogens will likely not spread from one patient to another with this arrangement. This information can potentially help to alleviate ethical concerns during a major health crisis, when the decision to co-ventilate must be made.

Many of these concerns have been addressed in a ventilator sharing protocol developed by an expert panel at Health and Human Services⁴ Ideally, patients would be cohorted based on their ventilator requirements and treated using pressure control to prevent 'volume stealing' and single-patient hypoxia. This could be monitored by individual tidal volume monitoring, and accidental extubation could be prevented by neuromuscular blockade.⁵ These measures help support the prior simulation by Neyman and Irvine¹ and animal study performed by Paladino *et al*² that coventilation is possible.¹ However, the safety of the antimicrobial filters and prevention of cross contamination are yet to be investigated.

These concerns highlight the ethical dilemmas of attempting to save multiple individuals at the expense of potential harm to the individual most likely to survive conventional mechanical ventilation.^{2-4,5} Appropriate allocation of ventilators and supplies can be most harrowing where critical care triage and resuscitation must occur simultaneously, all while trying to maintain supplies for future patient care.

The goal of our study is to address the potential cross contamination of infectious pathogens between multiple individuals on a single ventilator. Using common ventilator tubing, splitters and filters, we placed four artificial patient lungs in parallel on a shared ventilator to assess migration



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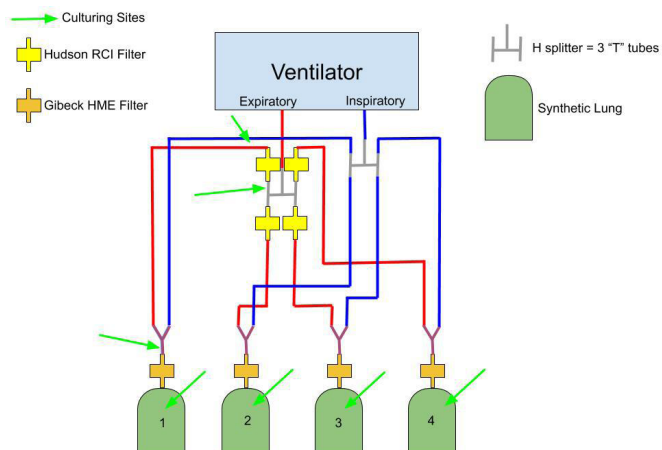


Figure 1 The ventilator circuit set-up. Green arrows indicate where cultures were collected.

of droplet-sized respiratory pathogens across respiratory circuit filters.

METHODS

Ventilatory circuit

The study employed an Evita XL ventilator (Dräger, Lübeck, Germany) connected to the shared circuit. Prior to building the multilimbed circuit, all tubing, connectors and non-filter parts were submerged in a 5000 ppm bleach bath for 20 min. The assembly then spent 24 hours under ultraviolet light to assure sterility and was assembled inside a ventilated hood to assure a pathogen-free circuit for this experiment. Airlife Tee-adapters (CareFusion, San Diego, California, USA) were arranged in an ‘H’ configuration (figure 1) to split the single inspiratory and expiratory ventilator limbs into four individual, parallel circuits in similar fashions as used by Neyman and Babcock in 2006 and Paladino *et al* in 2008.^{2,3} A 15 cm section of standard ventilator tubing was cut from a full tubing circuit to distance the splitter away from the ventilator connections. Four 2 L latex-free anaesthesia circuit breathing bags (Medline, Northfield, Illinois, USA) were fitted to the end of each individual tubing limb to serve as four simulated ‘patients’. Two L breathing bags were selected as they are able to accurately simulate adult patient tidal volumes, and could be reliably sterilised and cultured in an aseptic manner.

To prevent transmission of microbes, a Gibeck Heat and Moisture Exchanger (HME) filter set to HME (figure 2) (Teleflex, Wayne, Pennsylvania, USA) was inserted into each individual circuit just proximal to the patient (figure 3). For additional safety, our circuit also used four separate Hudson RCI bacterial/viral filters (Teleflex, Wayne, Pennsylvania, USA) connected to each proximal expiratory limb immediately prior to the shared ‘H’ splitter (figure 1). The location of the bacterial/viral filters was chosen to protect the expiratory limb H splitter and ventilator from cross contamination in case the HME filter was not 100% effective.

Ventilator settings

The ventilator was set on continuous mandatory ventilation volume control mode and run for 24 hours continuously. The ventilator passed a pre-use check to verify the absence of leak and calculate the tubing volume and compliance. The total tidal volume (V_T) set on the ventilator was 2000 cc to create an average individual volume of 500 cc for each respective ‘patient.’ Since all ‘lungs’ had similar compliances, the delivered V_T seen by each patient should have been equal and would simulate traditional human tidal volumes. The respiratory rate was set



Figure 2 Heat and moisture exchanger filter set to HME. HME, Moisture Exchanger.

to 16 with an FiO_2 of 21% and PEEP of 5 cm H_2O to simulate typical human ventilatory settings. The flow rate was set to auto-flow, so it was calculated breath to breath as needed with a fixed inspiratory time of 1.2 s.



Figure 3 HME filter attached to the ventilator bag.

Bacteriology and culture

An isolate of *Serratia marcescens* was used in this experiment. We employed 10^{10} cfu/g of lung tissue in accordance with prior investigations.^{6,7} An overnight growth of *S. marcescens* in 100 mL of Mueller Hinton broth was centrifuged and resuspended in 5 mL yielding a final concentration of 1.7×10^{10} cfu/mL of *S. marcescens* or approximately 8.5×10^{10} cfu. To prove the absence of *S. marcescens* at the start of the experiment, 50 mL of Mueller Hinton broth was instilled into sterile ‘patients’ two through four, agitated throughout the entire breathing bag, and then re-captured for incubation. Sterile gauze was placed inside of patient one in an attempt to simulate natural characteristics of lung parenchyma. The 5 mL of live bacterial culture was then instilled into patient one and distributed throughout the respiratory bag and gauze. The entire circuit was then attached to the ventilator and run for 24 hours continuously.

After the 24 hours trial was completed, each ‘patient’ was washed with 50 mL of Mueller Hinton broth. In addition, 20 mL of broth wash cultures were obtained from selective parts of the expiratory tubing in limb one. Tubing 15.2 cm long next to the HME filter from the first limb was cut from the circuit and broth was poured through this tube section while rotating it to wash down all sides. The 15.2 cm of tubing before entry into Hudson RCI filter was also cut-off and cultured in a similar fashion, as well as the connector piece after the Hudson RCI filter joining it to the H valve. We took these additional cultures to ascertain how far *S. marcescens* spread up the expiratory tubing in the event the culture taken adjacent to the HME filter on limb one demonstrated growth of our pathogen marker. All broth cultures were incubated at 37°C for 48 hours, with 1 mL subcultures performed at 24 hours on MacConkey agar to isolate gram-negative bacteria.

RESULTS

Preinoculation cultures of lungs two, three and four documented the absence of *S. marcescens* prior to the start of the experiment. Following inoculation of lung one and operating the ventilator for 24 hours, wash cultures of this lung confirmed the persistence of *S. marcescens* as expected. Wash cultures of lungs two, three and four collected at the termination of the experiment failed to demonstrate growth of *S. marcescens*. Cultures of the tubing next to the HME filter, the tubing proximal to the Hudson RCI filter, and the post-Hudson RCI filter expiratory limb connector also yielded no growth of *S. marcescens* after 24 and 48 hours of incubation.

DISCUSSION

It is a common belief that placing more than one individual on a single ventilator is a high-risk manoeuvre and should be avoided if possible. This action should only be attempted in extreme circumstances when there is a critical shortage of this resource.

Our findings suggest that droplet-sized pathogens likely will not spread from one infected patient to another using our shared ventilator circuit design as *S. marcescens* was not cultured from any section of the ventilator tubing or lungs beyond the first respiratory bag where it was instilled. We chose the HME filter and the bacterial/viral filters because they are ubiquitous and are rated 99.99% bacterial and viral filtration efficient. They should prevent passage of almost any infectious pathogen travelling within a respiratory droplet. All of the circuit components that we employed should be readily available in times of crisis.

Per personal correspondence with Teleflex, the HME filter and the bacterial/viral filters are 99.99% efficacious at filtering viral

and bacterial pathogens. Teleflex states that the HME filter was challenged with *Staphylococcus aureus* (bacteria size 0.8 µm), MS 2 Coliphage (virus size 0.025 µm), and *Mycobacterium tuberculosis* (bacteria size 0.3–0.6 µm), all of which confirmed its efficacy.

The design of our circuit architecture took advantage of the unidirectional flow of gas away from the ventilator, down the inspiratory limb. We propose this feature would help inhibit bacterial spread backwards from the infected lung into the circuit and therefore other patients. For this reason, we did not deploy filters on the inspiratory arms although the HME filter was strategically placed just proximal to the patient preventing migration of *S. marcescens* into both the inspiratory and expiratory tubing.

There are several notable limitations to our study. Respiratory pathogens can be transmitted via droplets greater than 10 µm being deposited on mucous membranes, aerosols less than 5 µm being inhaled into the lower respiratory tract, and direct contact of any size infectious particles with mucous membranes.⁸ The greatest concern for individuals on a shared ventilator is transmission of respiratory droplets and aerosols via the circuit. A study by Heuer *et al.*⁹ conclusively showed that most filters eliminate up to 99.9995% of viral particles and bioaerosol (minute droplets in air with a droplet size range of 0.78 to 9.0 µm). We did not directly test for the spread of viral particles such as COVID-19 or influenza. Instead, we picked *S. marcescens* as a strong surrogate due to its size. This pathogen is typically 0.5–0.8 µm × 0.9–2.0 µm, and we postulated that it would make a reliable surrogate to test the migration of any infectious aerosol particle through ventilator tubing and filters.¹⁰

The quantity of bacteria within our lungs was significantly higher than expected in a typical pneumonia patient. Our final bacterial load was equal to the number of bacteria that would be found in a lung 100% infected with pneumonia, as per clinical pneumonia studies.⁶ We did this so the filters’ efficacy would be challenged by the highest possible concentrations of bacteria that could be seen in a patient with pneumonia.

This is an in vitro study using four artificial 2 L Medline latex-free breathing bags to simulate lungs. As lung surrogates, all had equal resistance and compliance. In vivo, individuals have an infinite variety of lung compliances and resistances. It is unknown how various lung dynamics would influence the flow of gas and respiratory particles though the ventilator circuit and the filters. The pathology causing patients to require coventilation, that is, infectious versus traumatic lung injury could change the amount of secretions present as well as the likelihood of transmission. Additionally, we soaked the *S. marcescens*-broth mixture into a sterile gauze in an attempt to simulate lung parenchyma within the lung surrogates. The intent was to prevent desiccation of the inoculum. It is unknown if this manoeuvre would make aerosolisation any more or less likely.

We did not simulate coughing or suctioning. Both could aerosolise droplets of *S. marcescens*, propelling them into the circuit and spreading them between patients. We propose full paralysis and adequate sedation of patients on a shared ventilator to eliminate coughing.

The cultures from the four lungs were collected immediately after the ventilator was operated for 24 hours. The cultures taken from the cut tubing sections were collected 18 hours later. It is possible that these cultures may not be valid since they were performed 18 hours later.

Our ventilator circuit operated for 24 hours. We can only account for the efficacy of the filters in our configuration for that period of time. Future studies could address this concern by operating a ventilator setup for a longer period of time. Since

our experience finds patients afflicted with COVID-19 could be restricted to a ventilator for a week or more, this would be an important study to carry out. However, it is our hope that co-ventilation would only be used as a temporary bridge strategy for less than 24 hours until additional ventilators are procured, and not for the entirety of the patients' ventilator use.

Finally, we would like to acknowledge that this research study took place in New York City at the height of the COVID-19 pandemic. As such, we could not spare more ventilator tubing or filters to repeat the experiment due to the ethical concern of running out of equipment for actual patients. Ideally, this trial should be replicated multiple times to ensure reproducibility after the pandemic is over. Considering the scarcity of resources during a disaster, one may want to repeat this study using only a single filter, located just distal to the infection source to conserve supplies in the event another pandemic arises.

CONCLUSIONS

In this study, we demonstrated that there was no cross contamination of *S. marcescens* between circuit limbs or ventilator bags/simulated patients incorporating bacterial/viral filters when using one machine to ventilate four artificial patients. Therefore, we believe utilisation of our circuit architecture should prevent cross contamination of droplet-sized infectious agents while ventilating multiple people on the same ventilator.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

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