CORRESPONDENCE

Bacterial–viral filters to limit the spread of aerosolized respiratory pathogens during neonatal respiratory support in a pandemic era

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SCOPE OF THE DOCUMENT

The novel coronavirus disease 2019 has raised several questions about how to limit the spread of highly transmissible respiratory viruses. While guidelines and recommendations exist for adult patients, these cannot be extrapolated to infants and neonates, as neonatal respiratory support presents specific issues (e.g., high apparatus dead space compared to neonatal airways, high bias flows, humidified gases, etc.) that make the transmission of respiratory pathogen control particularly challenging. Three recent papers address the issues of pathogen transmission, aerosol-generating procedures, and infection control before, during, and after neonatal resuscitation1,2 and during different respiratory support modes in the neonatal intensive care unit.3

This document provides more detailed indications on how to use bacterial–viral filters to reduce the spread of respiratory pathogens from neonatal patients with acute respiratory infections receiving respiratory support, with a focus on the protection of the environment and healthcare workers.

INTRODUCTION TO AIR FILTERS

Bacterial–viral air filters are medical devices used in respiratory ventilators or breathing circuits to protect patients, equipment, and/or the environment from viruses and bacteria. They may be either electrostatic or mechanical, based on their working principle: electrostatic filters use an induced electrostatic charge to capture particles, while mechanical filters use a pleated porous membrane. Mechanical filters can reach higher filtration efficiency than electrostatic filters, but they impose higher airflow resistance.

Air filters are classified upon their efficiency: efficiency particulate air (EPA), high-efficiency particulate air (HEPA), and ultra-low penetration air filters retain a minimum of 99.95%, 99.97%, and 99.999% of 0.3 μm particles, respectively. Heat moisture and exchangers (HMEs) retain heat and humidity from exhaled air and return them to the patient during the following inspiration. HMEs also provide a filtration function that can be either electrostatic or mechanical, and they can be classified as either EPA or HEPA based on their filtration efficiency. HMEs are passive humidifiers and, as such, they should be placed at the inlet of the airway interface. HMEs must not be used with humidified gases because the humidity retained by the hygroscopic membrane may increase airflow resistance.4

Connecting a bacterial–viral filter to the breathing circuit modifies its mechanical characteristics: (1) it increases the compliance of the circuit; (2) it increases dead space if placed at the airway interface; (3) it adds a resistance that causes a pressure drop between the inlet (P1) and the outlet (P2) of the filter:

\[ P_2 = P_1 - R \times V' \]

The pressure drop increases with increasing filter resistance (R) and with flow rate (V'). The filter resistance may increase as particles and humidity are retained.

FILTERS WITHIN DOUBLE-LIMB BREATHING CIRCUITS

Air filters may be connected in different positions within a double-limb breathing circuit (Fig. 1).

Position 1

The bacterial–viral filter on the inspiratory limb has two functions: (1) protecting the equipment from the rare event of contamination with exhaled air, (2) protecting the patient in case he/she breathes room air through the safety valve that some ventilators open in case of sudden failure. The inspiratory filter does not prevent environmental contamination. The mechanical characteristics of inspiratory filters remain stable over time because the gas flowing through them is clean and dry. The pressure drop across the filter may affect the inspiratory flow and pressure waveforms. The high bias flows typically used in neonatal ventilators cause an additional pressure drop. Nevertheless, the alteration of inspiratory waveforms and the pressure drop associated with the bias flow should not significantly affect ventilation. If the ventilator measures the airway pressure at the Y-piece, it automatically compensates for the filter load. If not, the breathing circuit should be recalibrated with the filter in place, so that the ventilator estimates the mechanical properties of the breathing circuit and compensate measurements accordingly.

Position 2

A filter between the breathing circuit and the airway interface protects the patient, equipment, and environment from airborne contamination.5,6 HMEs should be placed only in position 2. This configuration increases dead space, thus affecting gas exchange. In adults, a filter between the Y-piece and the airway interface increases minute ventilation or arterial partial pressure of carbon dioxide.7 Position 2 should be avoided in neonates because filter dead space (e.g., 8–10 mL for the smallest filters) is very high compared with the patient tidal volume.8 The ventilator cannot detect the effects of a filter between the Y-piece and the airway interface. Therefore, monitoring ventilation waveforms over time is recommended to identify the possible consequences of increased filter resistance.

Positions 3 and 4

Expiratory filters prevent bacteria or virus transmission to the environment. They do not add dead space, but they increase
Bacterial–viral filters during manual ventilation

Self-inflating bag

A filter between the self-inflating bag and the airway interface represents the easiest solution to protect patients, equipment, and the environment from contamination. Use a filter with the lowest possible dead space. Neonatal HME filters may have a dead space as low as 8–10 mL. We suggest using an HME filter in this configuration because gases are not humidified.

T-piece

The high bias flow flowing through the PEEP valve of the T-piece may produce aerosolized pathogens that are dispersed at a long distance toward the operator. In a standard T-piece, the only possible filter position is at the inlet of the airway interface. Since this configuration adds dead space, we propose an alternative solution, which consists in using a double-limb circuit, connecting the T-piece PEEP valve at the end of the expiratory line, and closing the patient outlet of the T-piece (Fig. 2).

Non-invasive ventilation

Non-invasive respiratory support is an aerosol-generating procedure, and caution is required when managing it. We suggest administering non-invasive respiratory support using a mechanical ventilator with a double-limb breathing circuit and an expiratory filter connected as described above, whenever possible. To our knowledge, no studies evaluated the dispersion of aerosolized pathogens while using jet systems (e.g., Benveniste valve or Infant Flow Driver system) or bubble continuous positive airway pressure. These devices may increase pathogen dispersion, and
connecting an expiratory filter to them is not feasible. In adults, high flow nasal therapy does not increase the risk infection, if associated with good seal. However, in neonates, a gas leak from the nares should be allowed. During non-invasive respiratory support, pathogens may spread through nose and mouth leaks, thus covering the infant’s nose and mouth with a surgical mask may trap or reduce the velocity of airborne particles. Non-invasive respiratory support should be administered in appropriate airborne isolation rooms.

**FUTURE PERSPECTIVES**

Future studies should evaluate the extent of pathogen dispersion during different types of neonatal respiratory support and should investigate whether the use of viral/bacterial filters in the breathing circuit can significantly affect ventilation and reduce the spread.

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**AUTHOR CONTRIBUTIONS**

E.Z. gave substantial contributions to the conception and design of the manuscript and acquisition of literature data; she drafted the article and gave her approval of the manuscript version to be published. C.V. gave substantial contributions to the conception and design of the manuscript and acquisition of literature data; she helped in drafting the article and gave her approval of the version to be published. C.G. gave substantial and original contributions to the conception and design of the manuscript; he revised the manuscript critically for important intellectual content and gave his approval of the version to be published. F.M. gave substantial contributions to the conception and design of the manuscript and revising the manuscript critically for important intellectual content; he gave his approval of the version to be published. C.V. gave substantial and original contributions to conception and design of the manuscript and acquisition of literature data; she revised the manuscript critically for important intellectual content and gave her approval of the version to be published.

**ADDITIONAL INFORMATION**

**Competing interests:** The authors declare no competing interests.

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