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RESEARCH REPORT

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A simple screening test of filtration efficiency for protecting the gas sampling line from coronavirus using fluorescent microspheres

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Abstract

Background: During the coronavirus pandemic, preventing contamination of the anesthesia machine, critical to avoid cross-contamination between patients, has proven challenging when treating premature infants and neonates. While attaching a HEPA filter to the endotracheal tube will protect the anesthesia machine and the gas sampling line from contamination, this contribution to the dead space makes ventilation of these small patients challenging. Direct filtration of the gas sampling line eliminates this problem; however, appropriate filters are not readily available.

Aims: Identify a small filter capable of filtering out particles of a size similar to the SARS-CoV-2 virus for the gas sampling line.

Methods: We used fluorescence microspheres suspended in a solution for a challenge test to determine the filtration efficiency of various filters. The microspheres varied in diameter (0.02 μm, 0.042 μm, 0.109 μm, and 0.989 μm). A fluorescence plate reader was used to evaluate the degree of fluorescence intensity in the flow-through from various filters and referenced to the fluorescence intensity of the input.

Results: AHEPA filter, as recommended as an anti-viral filter, effectively filtered all the particles tested. The B. Braun PERIFIX Flat Epidural Filter was the second most effective filter, filtering particles larger than 0.042 μm. Other filters tested did not filter fluorescence microspheres equivalent in size to a single coronavirus particle (0.07 μm).

Conclusions: Although the Food and Drug Administration (FDA) has not approved the Flat Epidural Filter for use as an anesthesia machine gas filter, our simple challenge test suggests that it could be used to effectively filter the anesthesia gas sampling line.

KEYWORDS

anesthesia machine, coronavirus, dead space, filter, fluorescence microsphere

1 | INTRODUCTION

The Coronavirus Disease 19 (COVID-19) is the disease caused by coronavirus-2 (SARS-CoV-2). A series of atypical respiratory disease caused by this novel virus was first reported in Wuhan, China in December 2019. The virus has rapidly spread to over 200 countries, and the World Health Organization (WHO) declared a pandemic in February 2020.[1]

Amidst this pandemic, patients actively suffering from COVID-19 may need surgical intervention under general anesthesia. Additionally, the massive influx of COVID-19 patients to intensive care units (ICUs) has resulted in a shortage of ventilators

in some hospitals and anesthesia machines in operating rooms have been used to mechanically ventilate patients with pulmonary dysfunction. To mitigate the spread of this virus, protecting the anesthesia machine from contamination has become of paramount importance.

The Draeger Apollo Anesthesia Machine has the gas flows arranged such that the gas sampling line returns the sampled gas back to the breathing circuit. These gases need to be filtered to avoid contaminating the machine. Draeger has recommended placing a filter before the gas sampling line but notes that this recommendation is for "adults only"(Figure 1).[2] As a pediatric institution, this recommendation cannot be routinely used because the direct connection of the HEPA filter to the endotracheal tube results in an increase in the dead space, which may be too large for premature infants or very small neonates. The alternative setup (Figure 2)[2] leaves the gas sample line unfiltered. Finding an appropriate filter for this line has proven to be a challenge.

The coronavirus is usually transmitted by droplet or aerosolized and not in the free state. Aerosolized particles are generally 1-4 μm,[3] larger than the diameter of individual viruses (0.07 μm).[4] The Anesthesia Patient Safety Foundation (APSF) has recommended using a 0.2 μm epidural filter on the gas sampling line as an alternative.[5] It is unknown whether it is possible for the virus to be present as a single particle in the circuit of the anesthesia machine. With this concern, we examined the filtering capabilities of several types of filters that might be used to protect the gas sampling line.

What is already known?

Certain anesthesia machines are designed with the gas sampling line returning the sampled gas back to the breathing circuit. During the coronavirus pandemic, it became apparent that when providing anesthesia for small infants, this line needs to be filtered to protect the anesthesia machine from viral contamination. Commercial filters designed specifically for this purpose are not readily available.

What this article adds?

A simple screening test was developed to provide guidance as to which filters might be suitable barriers to prevent viral contamination of anesthesia machines. The results support the recommendation by ASPF that placing an epidural flat filter on the gas sampling line may potentially reduce the risk of contaminating an anesthesia machine with particles of a size similar to the SARS-CoV-2 virus when a larger HEPA filter might hinder patient care.

2 | METHODS

2.1 | Assessment of filters using fluorescence microsphere-based challenge test

To determine the efficiency of filtration by various commercially available filters as well as a departmental engineered stopcock filter, we used fluorescence microspheres of 0.020 μm, 0.042 μm, 0.109 μm, and 0.989 μm in diameter (Bangs Laboratory Inc). The stock microsphere solution was diluted in water with 1:200 ratio. This diluted microsphere solution was used as an input to various filters with a flow rate of 2 mL/min, and flow-through was collected. As a negative control, water was used as an input as well. The experiment was performed in a room with temperature of 20°C and humidity of 30%. 200 μL of the flow-through solution was aliquoted to the 96-well microplate and subjected to fluorescence-based assay (excitation 485 nm and emission 535 nm) using Synergy plate reader (Bio Tek Instruments) to obtain fluorescence intensity (FI).

The efficiency of filtration (Ef) is defined as

[(FI of microsphere input − FI of water) − (FI of flow-through of microsphere solution − FI of water)]/[FI of microsphere input − FI of water].

Because of [FI of water/FI of microsphere input] × 100 (%) < 0.1%, Ef is simplified as;

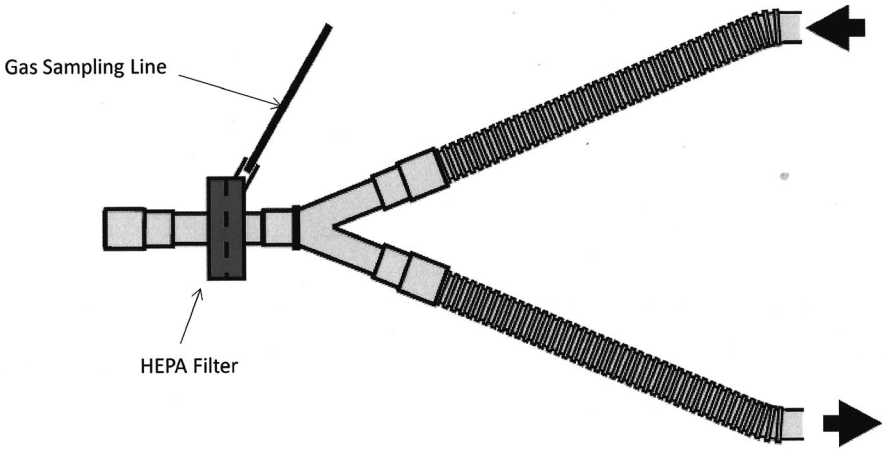

FIGURE 1 System setup recommendations for confirmed or highly suspected SARS-CoV-2 adult patients. (Modified from Customer Letter: SARS-CoV-2 and handling of Dräger Anesthesia Workstations https://www.draeger.com/Library/Content/SARS-CoV-2-and-handling-of-Draeger-Anesthesia-Workstations.pdf)

Ef = [(FI of microsphere input − FI of flow-through)/FI of microsphere input] × 100 (%).

The filters we studied included the B. Braun PERIFIX 0.2 μm Flat Epidural Filter (B. Braun), HEPA Filter (Vyaire Medical), AirLife Nonconductive respiratory therapy filter (Vyaire Medical), PES(Polyethersulfone) Syringe Chromatography Filter(Tisch Scientific), Capnograph filter (Hydrophobic Disc Filter. Flexicare; Wales, UK), Stopcock filter (This filter was assembled in the Department using a Medex Stopcock packed with two (2) 3/8 inch squares of the Vyaire HEPA filter material), and Draeger filter MX08834 (Draeger) (Figure 3). For filters that have directionality, only one way was tested according to the use.

2.2 | Analysis

Analysis was performed using PRISM5 software (GraphPad).

3 | RESULTS

Test results are summarized in Figure 4 and Table 1. The table includes the viral filtration efficiency (VFE) for those filters that have the information readily available.

We found the following for each filter.

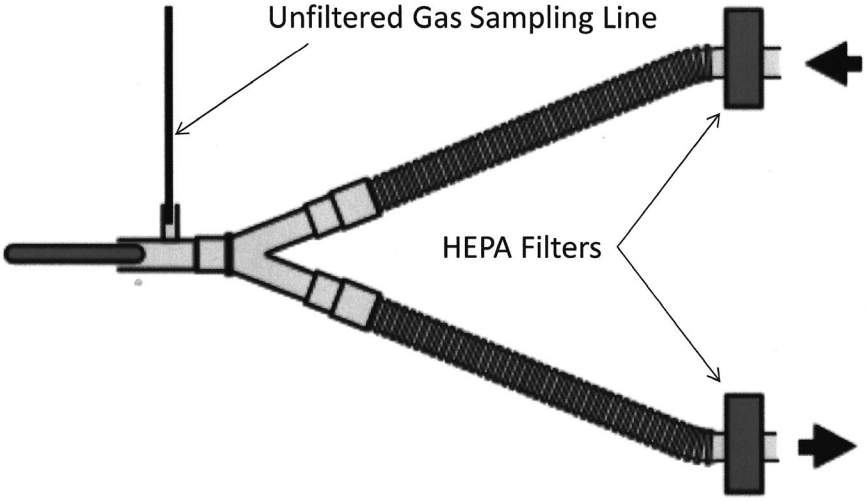

FIGURE 2 System setup recommendations for confirmed or highly suspected SARS-CoV-2 neonatal patients. (Modified from Customer Letter: SARS-CoV-2 and handling of Dräger Anesthesia Workstations https://www.draeger.com/Library/Content/SARS-CoV-2-and-handling-of-Draeger-Anesthesia-Workstations.pdf)

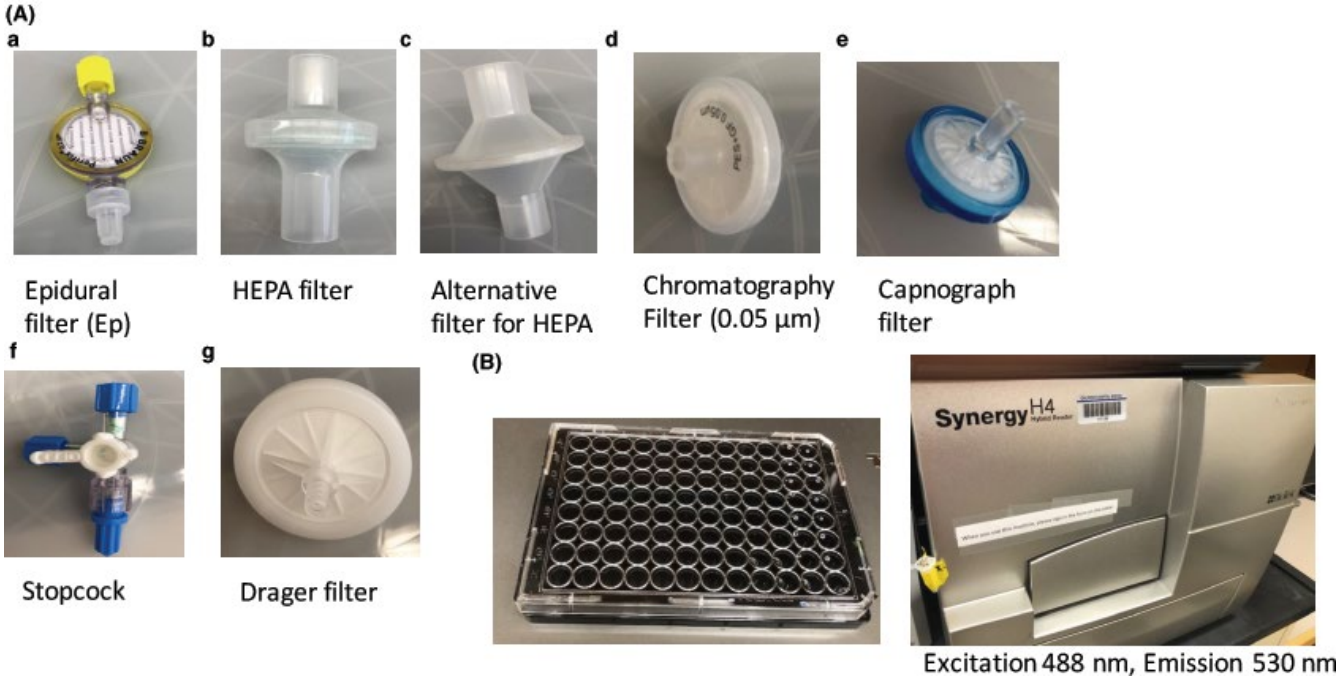

FIGURE 3 The type of filters tested in our study and assay equipment. A, Types of filter tested are shown. B, Flow-through was measured as described in the method using the plate and machine shown [Colour figure can be viewed at wileyonlinelibrary.com]

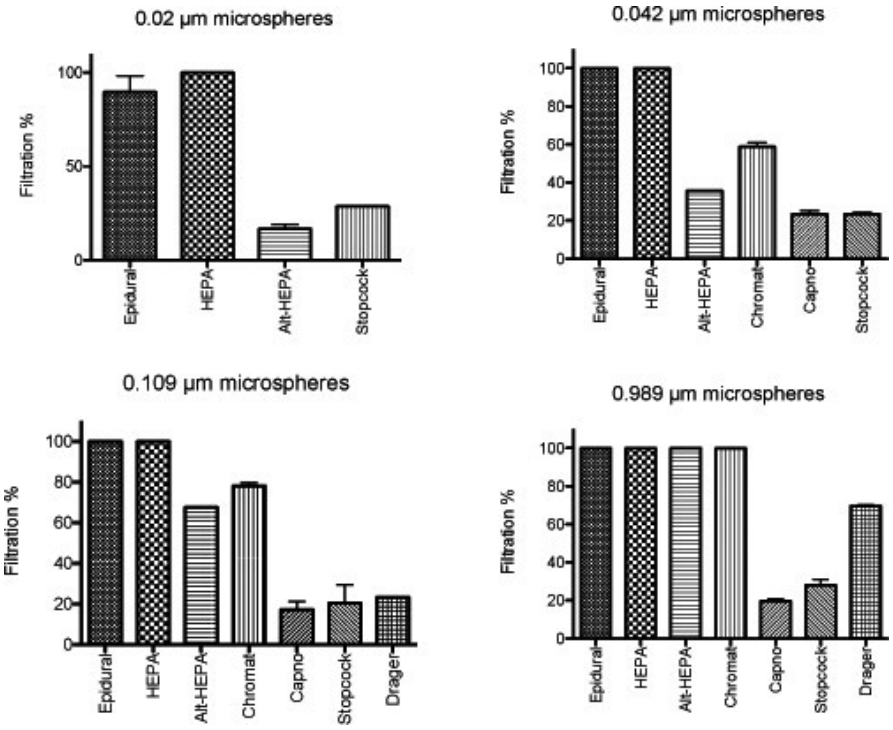

FIGURE 4 The filtration efficiency of various filters. We have shown the filtration efficiency of various filters. Data were shown as mean ± SD of triplicates of a representative data of two independent experiments

3.1 | HEPA filter

HEPA filter completely filtered microspheres of all the sizes tested.

3.2 | Non-HEPA filters

3.2.1 | B Braun PERIFIX Epidural filter

The epidural filter completely filtered the 0.04, 0.1, and 1.0 µm fluorescence microspheres. 0.02 µm microspheres were filtered with the efficiency of 82%-92%.

3.2.2 | Nonconductive respiratory therapy filter

Nonconductive respiratory therapy filter completely filtered 1 µm microspheres. The filtration efficiency of 0.1 µm microspheres was around 70%. The filtration efficiency of 0.04 µm microspheres was 40%. Only 20% of 0.02 µm microspheres were filtered.

3.2.3 | PES Syringe Chromatography filter

The chromatography filter completely filtered 1 µm microspheres. For 0.1 µm microspheres, the filtration efficiency was around 80% and 60% for 0.04 µm microspheres. Because the filter size was 0.05 µm, we did not examine using 0.02 µm microsphere.

3.2.4 | Capnograph filter

Capnography filter was tested using 0.04 µm, 0.1 µm, and 1 µm microspheres. It filtered only 20% of each type of microsphere.

3.2.5 | Stopcock filter

The filtration efficiency was around 20%-30% for all four sizes of the microspheres tested.

3.2.6 | Drager filter

Drager filter was also tested for 0.1 µm and 1 µm microspheres. 70% of 1 µm microspheres were filtered, while only 20% of 0.1 µm microspheres were filtered.

4 | DISCUSSION

With the advent of the COVID, pandemic came concerns that patients actively suffering from COVID-19 might need surgical intervention under general anesthesia and anesthesia machines could become vectors in the transmission of the disease. Guidelines were posted by manufactures[2] on what precautions were appropriate to limit the spread of the infection. The Draeger Apollo Anesthesia Machine has the gas flows arranged such that the gas sampling line returns the sampled gas back to the breathing circuit. This was designed in consideration of providing low

TABLE 1 Filtration efficiency based on fluorescence microsphere challenge test

	0.02 μm	0.042 μm	0.109 μm	0.989 μm
HEPA filter (VFE 99.999%)	99.9%	99.9%	99.9%	99.8%
Epidural filter	89.6%	99.9%	99.9%	99.9%
Nonconductive respiratory therapy filter (VFE 99.7%)	16.6%	35.7%	67.6%	99.9%
PES syringe chromatography filter	n/a	58.8%	78.1%	99.9%
Capnograph filter	n/a	23.4%	17.3%	19.6%
Stopcock filter	28.6%	23.4%	20.4%	28.0%
Drager filter	n/a	n/a	23.3%	69.6%

flow anesthesia. These gases are filtered by the WaterLock2 (Drager) water trap which is also used to mitigate water from getting into the multi-gas sensor of the Apollo machine. The filters in the Draeger water traps are very similar to those used by GE (rated at VFE 99.999% efficiency), but because Draeger had not yet received the results from the independent laboratory testing their filters,[6] the company declined to recommend using their anesthesia machines without additional filtration. (As of 5/5/2020, the testing was completed and the Waterlock 2 water trap was found to have a VFE of 99.99981%).[7] In the interim, the APSF offered some guidance by suggestion using an epidural filter on this line.[5] However, this recommendation was never actually validated and the likelihood of that happening in a timely fashion was low. Additionally, once the filters were introduced into clinical practice, it became apparent that as a case progressed and the filters became saturated with moisture the fidelity of the end-tidal Co2 tracing diminished significantly to the point where the filter would need to be replaced. This left the faculty clamoring for safe alternative for filtering the gas sampling line.

Complete testing of filters is a complex, and laborious process requires specialized equipment and works with live viruses and bacteria.[8] What was needed was a procedure that could provide some guidance as to which filter might be most appropriate. Taking one aspect of the testing protocol, the challenge test,[9] the filtering capacity of the various filters under consideration was determined using fluorescence microspheres of a similar size to the novel SARS-CoV-2. While this test could not determine whether the filters were actually safe to filter out virus particles, it was used to eliminate those filters that clearly would not pass the more rigorous testing.

The Vyaire HEPA filter was completely effective at filtering out all of the particles tested. While there are HEPA filters manufactured that add as little as 10 mL of dead space, these were not available for testing. This particular filter adds 30 mL of dead space when placed between the endotracheal tube and the "Y" connector (Figure 1),[2] and this can be an issue when ventilating premature infants and neonates. Direct filtering of the gas sampling line avoids this problem. The other filters tested were all considered for direct filtering of the gas sampling line.

The stopcock filter had an efficiency around 20%-30%, similar to that of the capnograph filter. Based on our methodology, the epidural filter had the second best filtration efficiency following the HEPA filter. It was therefore used to protect our Draeger machines when the HEPA filters at the "Y" connector contributed too much dead space to the circuit. It must be emphasized that this application of epidural filters has not been approved by the Food and Drug Administration (FDA) and was only considered as an alternative when the approved methods for protecting the anesthesia machine from contamination would hinder patient care.

We have successfully used the epidural filters with small neonates; however, as already noted, these filters do become saturated with moisture and need to be replaced during longer cases.

When changing the epidural filter, respirations should be suspended to avoid gas from the sampling line escaping into the environment. This is theoretically important because viral particles, if expelled from tubing, can stick to environmental surfaces, which can be an additional source of viral transmission. Viable SARS-CoV-2 virus has been found up to 72 hours after application to plastic and stainless steel surfaces.[1] Placing a heat moisture exchange for a small child may be considered to avoid water traveling into the epidural filter. However, this may further diminish the fidelity of the CO_2 tracing.

One major shortcoming of this study is that it is a static laboratory test using a microsphere containing solution. We did not test the filter with nebulized microspheres, which is more relevant to real-world clinical scenarios. As previously tested to filter influenza A (H1N1), an air stream model using aerosol human influenza virus A(H1N1) model would provide more accurate if we consider the SARS-CoV-2 in an aerosol.[10] However, there are no good data demonstrating how the virus might be conducted through the gas sampling tubing to the filtration devices. There is some evidence to suggest that filters might allow the free passage of pathogens once saturated with moisture.[11] Testing microspheres of the virus size could be important, as the virus may exist as a single particle in solution. The epidural filter efficiently filtered the microsphere smaller than a single viral particle. Another issue is that we did not test using live virus. Testing the viral load using post-filter solution would provide the most accurate assessment. A future study needs to be done by testing viral loads.

5 | CONCLUSION

Here, we reported a simple screening challenge test of filtration efficiency using fluorescent microspheres. Our test supports the recommendation by ASPF that placing an epidural flat filter on the gas sampling line may potentially reduce the risk of contaminating an anesthesia machine with particles of a size similar to the SARS-CoV-2 virus when a larger HEPA filter might hinder patient care.

CONFLICT OF INTEREST

None.

AUTHOR CONTRIBUTIONS

RMB: Designed the study and wrote the manuscript. KY: Designed the study, performed the experiment, and wrote the manuscript.

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