



Filter Considerations in the COVID-19 Era

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Company Statement

This white paper is shared with our health care colleagues to increase knowledge about filtration in mechanical ventilation during the COVID-19 crisis. This paper reflects a literature review. The selection and use of filters should first be reviewed and evaluated by each facility's medical and administrative staff, in consultation with manufacturers' instructions for use with its respective machinery, before implementation.

Introduction

As the COVID-19 pandemic evolves, filtration of mechanical ventilation, such as used in intensive care and anesthesia settings, has become an essential factor in infection control. Although face mask respirators are subject to internationally recognized standards and testing based on MPPS measures, filters in breathing circuits are not. Currently, no U.S. regulations or guidelines address the use of filters in a breathing system to shield the spread of infectious pathogens to or from patients. Moreover, as of the beginning of May 2020, no data exist examining the efficacy of breathing circuit filters in preventing SARS-CoV-2 transmission to patients or healthcare workers. This report aims to provide additional insight into filter design, function, efficacy and duration of use in clinical applications, including when filter conservation is necessary due to supply shortages.

Path to Contemporary Filters

Protecting human airways with some form of filter has documented roots to the first century C.E.¹ The modern era of respirator protection originated within the mining industry. In 1919, the U.S. Bureau of Mines (USBM) issued the first regulations for self-contained breath apparatus respirators, followed by its first certification in 1920.

In the early 1930s, limited use of respirator protection contributed to the silicosis-related deaths during the construction drilling of the Hawk's Nest Tunnel in West Virginia, considered "one of the worst industrial tragedies in the history of the United States."² Subsequently, USBM issued in 1934 the first standards for approval of respirators for dust, fume and mist particulates, 30 CFR Part 14, Schedule 21.³

During World War II, the need for protection against biological, chemical and radiological agents, including nuclear weapon emissions, drove military research and requirements for avoiding contamination during respiration.⁴ Filters in gas masks developed by the U.S. Army Chemical Corps, improving upon filters found in German gas mask canisters, are recognized today as the precursor of the high-efficiency particulate air (HEPA) filter, with capabilities to capture a majority of airborne particles, including pathogens.^{5,6}

Pathogen Transmission

PATHOGEN SIZES

Viruses, like the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) that causes coronavirus disease (COVID-19), are measured in nanometers (nm). One nm is equivalent to 1/1,000th of a micron (μm), the unit of measure used in filtration materials.⁷ A single μm is one-millionth of a meter (m).⁸

A single virion can range from 0.02 to 0.4 μm in diameter, depending on the viral strain.⁹ The diameter of a SARS-CoV-2 virion is between 0.06 to 0.14 μm .¹⁰

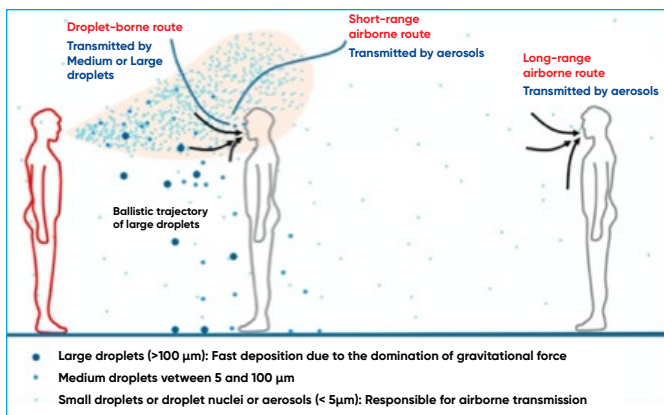
In comparison, a coliphage T1 virion is 0.017 μm ; hepatitis A, 0.02 μm ; hepatitis C, 0.03 μm ; and HIV, 0.08 μm .^{11,12} In contrast, the diameter of an individual bacterium of *Staphylococcus aureus* can be as large as 1.0 μm , while lymphocytes range from 5.0 to 8.0 μm , and a red blood cell is 5.0 μm .¹³

PARTICLE DEFINITIONS

While SARS-CoV-2 may spread to a person who touches a contaminated surface, the primary route is from an infected person who sneezes, coughs or talks and thus generates a respiratory-based transmission that enables someone else to inhale the virus.¹⁴ Technically, the Centers for Disease Control and Prevention (CDC) considers such respiratory modes as contact transmissions in comparison to airborne transmissions, which the agency defines as disseminations that "may be dispersed over long distances by air currents and may be inhaled by susceptible individuals who have not had face-to-face contact with (or been in the same room with) the infectious individual."¹⁵

Respiratory transmissions occur via carrier particles, classified as either a droplet or an aerosol.

- **Respiratory droplets** are particles sized larger than 5 to 10 μm in diameter.^{16,17} Respiratory droplets usually have short transmission distances, hence social distancing guidelines to remain six feet apart.¹⁸ Current evidence from peer-reviewed scientific studies suggests that SARS-CoV-2 is "primarily transmitted between people through respiratory droplets and contact routes."¹⁹
- **Aerosols** are particles sized smaller than 5 μm .²⁰ These particles, also referred to as airborne nuclei, have the ability "to remain in the air for long periods of time and be transmitted to others over distances greater than 1 meter."²¹ In experimental settings, aerosols of SARS-CoV-2 concentrations similar to that sampled from the human respiratory tract remained viable for a minimum of three hours.²²



Small aerosols (<5 μm) are responsible for the short- and long-range airborne transmission, and indirect contact route. Large droplets (>5 μm) are responsible for direct spray and indirect contact routes.⁹⁹

To cause disease, a particle, regardless of its size, must transport the infectious virus and this virus must survive long enough to reach a host.²³

Studies that explored the relationship between particle size and infectiousness have documented larger particles have the capability of transmitting more infectious and total virion concentrations.²⁴ Survivability of viruses in large particles, 0.3 to 0.45 μm, is significantly higher than of those contained in smaller particles, 0.1 to 0.2 μm, which are themselves close in size to that of individual virions.²⁵

However, smaller particles can permit viral survivability of several hours. In a controlled laboratory setting, investigator-generated aerosols with carrier particles sized less than 5 μm carried after three hours 10^{2.7} SARS-CoV-2 virions per milliliter at a concentration of the 50 percent tissue-culture infectious dose (TCID₅₀), a standard measure of infectious virus titer that defines the quantity of virus necessary to kill or render a cytopathic effect on half of the infected host cells.²⁶

SARS-CoV-2 TRANSMISSION

Transmission of SARS-CoV-2 is possible among individuals in close proximity, such as during medical procedures, based on real-world data and laboratory experiments. An analysis of more

than 75,000 patients in China with COVID-19 did not document airborne transmission of the virus, but did lead the World Health Organization to suggest on March 29, 2020, such a risk exists:²⁷

“In the context of COVID-19, airborne transmission may be possible in specific circumstances and settings in which procedures or support treatments that generate aerosols are performed; i.e., endotracheal intubation, bronchoscopy, open suctioning, administration of nebulized treatment, manual ventilation before intubation, turning the patient to the prone position, disconnecting the patient from the ventilator, non-invasive positive-pressure ventilation, tracheostomy, and cardiopulmonary resuscitation.”²⁸

Moreover, researchers have noted that when carrier droplets evaporate into residues or nuclei, the material is capable of remaining suspended in air for hours and, subject to airflow including room ventilation, to travel large distances.

Spread from infectious residues is subject to temperature and humidity, as well as air dynamics. In a laboratory experiment, the dynamics of exhaled turbulent puff clouds reached speeds of 33 to 100 feet per second(s) (10 to 30 m/s), creating a residue cloud spanning 23 to 27 feet (7 to 8 m).²⁹ In the real world setting of hospital rooms of patients with COVID-19 in China, airflow displacement of SARS-CoV-2 particles appears to have enabled transmission of airborne deposits recovered from the room ventilation systems.³⁰

Filter Design, Composition and Mechanics

Artificial breathing systems, or circuits, substitute for the upper airways during intensive care or anesthesia of patients who cannot breathe adequately on their own. In so doing, the circuits rely on disposable filters for purification and use heat and moisture exchangers (HME) for warmth and humidification.

Filters differ in their composition and form and the physical laws governing their mechanical ability to capture pathogens and particles.

DESIGN AND COMPOSITION

Under the usual pressures of mechanical ventilation in breathing circuits, filters vary in their ability to capture gas-borne pathogens, particles, contaminated condensate, infected sputum or circulated air.³¹ This variation stems from the design and composition of the filters, which are a matted three-dimensional network of fibers.

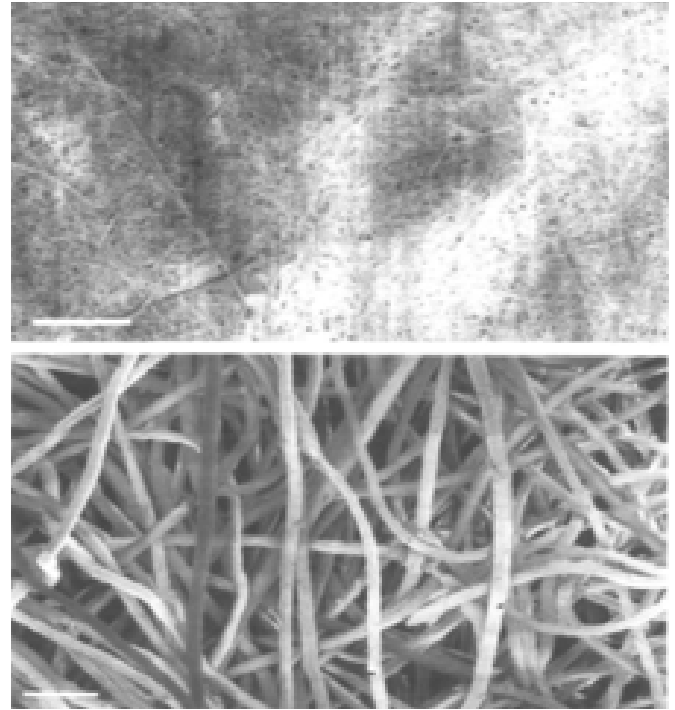
HME and filter combinations can group into six main categories of breathing systems:³²

1. HME with no filter
2. Electrostatic filter only
3. Pleated filter only
4. Electrostatic filter with HME
5. Pleated filter with HME
6. Combined electrostatic and pleated filter with HMS

Systems that use a filter and an HME, like 4, 5 and 6 above, may be called HME filters or HMEFs.

Pleated filters feature high-density fiber hydrophobic membranes folded so that a large surface area is available in a smaller dimension. The small pores of the membrane prevent the passing of pathogens alone or of water droplets, which may carry pathogens, without impeding airflow.³³ Pleated filters also may be referred to as mechanical.

In contrast, **electrostatic filters** use low-density fiber, but the material has a high electrostatic charge, either fibrillated or triboelectric-charged. Fibrillated fibers carry a charge preserved from splitting sheets of electrostatically charged plastic called polypropylene. Triboelectric-charged fibers form from rubbing together fibers of polypropylene and modified acrylic.³⁴ The positive and negative electrostatic charges of the fibers attract bacteria, viruses and small-sized, low-mass particles that move with low air velocities such during normal breathing.^{35,36}



Scanning electron micrographs demonstrating difference in pore size of the filter. Top: Hydrophobic membrane. Bottom: Electret felt. The scale bar is 100 μm in each.¹⁰⁰

MECHANICS

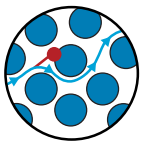
The success of filter membrane function depends not only on its design and composition, but also on the size and nature of the target pathogen or particles. This success is the result of physics, specifically the size- and movement-dependent behavior of particles relative to a filter, as defined in work first undertaken by Langmuir in the early 1940s for the U.S. Army, and then modified by Ramskill and Anderson in 1951.^{37,38}

Filters can capture particles suspended within a moving airflow by impact inertia, interception or diffusion. Filters capture particles ranging from 1 μm to larger than 10 μm in diameter via inertial impact and interception, while smaller low-mass particles, 0.1 to 1.0 μm , are subject to diffusion.

- Particles travel in a defined path can impact target filters due to **inertia** effects that keep the particles' routes unchanged, not unlike when a moving car is unable to change lanes and then collides with a vehicle merging from an on-ramp.³⁹

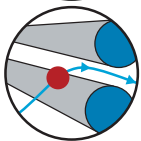
- **Interception** capture by a filter are similar but occur when particles and the filter offset slightly from one another yet their proximity permits a "grab," not unlike a water droplet collecting a particle.⁴⁰
- Brownian **diffusion** defines how small particles move randomly after striking gas molecules, effectively increasing particle dimension and making them easy to catch by filter membrane fibers.^{41,42}

However, the combined effects of interception, inertia and diffusion have the least ability to enable efficiently capture particles sized 0.3 μm , well within the range of aerosols.⁴³ Subsequently, 0.3 μm is a demarcation for filtration and is referred to as the most penetrating particle size (MPPS) for its ability to slip through the individual fibers in a filter without capture.



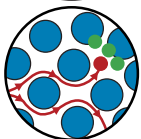
INERTIAL IMPACTION:

Particles are collected as they travel in a straight path and collide with a fiber. Air continues to flow around the fiber.



INTERCEPTION:

Particles are collected whenever they touch a fiber as they traverse the media.



DIFFUSION:

Particles are collected as they travel from areas of high airflow to areas of low airflow.

Different mechanisms of particle capture by filters.¹⁰¹

Filtration Standards

Although face mask respirators are subject to internationally recognized standards and testing based on MPPS measures (Table 1), filters in breathing circuits are not.^{44,45} Currently, no U.S. regulations or guidelines require a standard approach or threshold to address the use of filters in a breathing system to shield the spread of infectious pathogens to or from patients.⁴⁶

HEPA AND B/V FILTERS

The ability to reduce transmission of particles or pathogens can define filter types.

HEPA specifically refers to the efficiency of capturing particles with a MPPS diameter size of 0.3 μm .⁴⁷ Bacterial and viral (B/V) filters are defined by their ability to filter particles with a diameter size of 3.0 μm , and are used to reduce the risk of cross-contamination of pathogens that cause disease, including for patients that may be immunocompromised, infectious or of unknown infection status.⁴⁸

PATHOGEN CROSS-CONTAMINATION POTENTIAL

Cross-contamination via breathing circuits without filters in critical care or anesthesia is a serious concern with the potential for high transmission rates across a spectrum of pathogens.

Mycobacterium tuberculosis (TB) and severe acute respiratory syndrome (SARS) virus historically have been some of the most concerning respiratory pathogens, outside of influenza strains, with regard to the use of mechanical breathing systems. However, contact transmission of hepatitis C virus (HCV) also is possible via circuits.⁴⁹

- **TB**, if active and untreated, can spread via sneezing, coughing or talking from one person to infect 10 to 15 people annually. Just 10 bacilli comprise a potent, infectious dose, and patient-patient and patient-healthcare professional transmissions have been documented. After use, TB bacilli can remain moving within breathing circuit air unless the gas flow is halted for at least an hour. Both pleated hydrophobic and electrostatic filters are capable of capturing TB particles if they have high enough filter efficiencies.⁵⁰
- **SARS** is a virus spread via contact and respiratory transmission of infectious droplets, with documented cross-contamination from patient to health care professionals, despite the use of high-efficiency personal protective equipment. Electrostatic filters when wet can permit the passage of the SARS virus.⁵¹

- **Influenza A** viral strains of the avian flu (H5N1) and swine flu (H1N1) spread via respiratory droplets. Documented patient-healthcare professional transmission from a distance of 1 m have been documented. High-efficiency pleated hydrophobic filters can capture influenza particles.⁵²
- **HCV** has passed via unfiltered breathing circuits to be a source of cross-contamination. Without a filter barrier, equipment-enabled infection can occur from “the transmission of liquid-borne microbes present in sputum particularly, blood-stained.”⁵³ Pleated hydrophobic filters have consistently prevented HCV spread within circuits.⁵⁴

Filtration Testing

PENETRATION AND EFFICIENCY

The percentage of particles able to pass entirely through a filter defines its percent of penetration. If an airflow directs 1,000 particles to a filter and only five particles pass through, the penetration is 0.5 percent. The corollary percent of trapped

particles defines the filter’s efficiency, which is 99.5 percent for this example. The penetration and efficiency ratings of a filter should include the particle size used during testing.⁵⁵

Early filter testing by the U.S. Army Chemical Corps for World War II gas mask filters used smoke to evaluate penetration and capturing efficiency. Today, a variety of tests are employed, including one using the oily liquid di-octyl-phthalate (DOP) because its particulates are uniformly of the MPPS 0.3 µm size.⁵⁶

ASTM/EN

The American Society for Testing and Materials (ASTM) and the European Standard (EN) both have issued guidance that requires testing for face masks, which the U.S. Food and Drug Administration uses to evaluate submissions for devices seeking market clearance in the United States.^{57,58,59} U.S.-based Nelson Laboratories helped developed the **Bacterial Filtration Efficiency (BFE)** test that meets the guidance standards and is used to evaluate not only masks, but air filters, surgical gowns and caps.⁶⁰

Face Mask Regulations

The U.S. National Institute for Occupational Safety and Health (NIOSH) will not approve any face mask filter with an efficiency of less than 95 percent. Filters are labelled as 95, 99 and 100, respectively, to correspond with efficiencies of 95.0, 99.95, and 99.97 percent. A rating of 99.999 percent denotes of 100,000 particles only 1 has potential to penetrate. Filters also are classified with NIOSH-designated prefixes based on resistance to oil, including not resistant (N), resistant (R) and oil-proof (P). As a result, NIOSH-approved filtering has seven filter classes (Table 1).^{102,103}

Table 1. NIOSH-Approved Filtering Facepiece Classifications¹⁰⁴

N95	Filters at least 95% of airborne particles. Not resistant to oil.
Surgical N95	NIOSH-approved N95 respirator cleared by the Food and Drug Administration as a surgical mask.
N99	Filters at least 99% of airborne particles. Not resistant to oil.
N100	Filters at least 99.97% of airborne particles. Not resistant to oil.
R95	Filters at least 95% of airborne particles. Somewhat resistant to oil.
P95	Filters at least 95% of airborne particles. Strongly resistant to oil.
P99	Filters at least 99% of airborne particles. Strongly resistant to oil.

Because of its long-term use with only minor modifications, the BFE test serves as a validated, reproducible reference for comparing filtration materials. The BFE test compares bacterial counts in downstream aerosols to that in control aerosols using *Staphylococcus aureus* as the challenge organism delivered at a constant airflow rate of 28.3 liters per minute (LPM) or 1 cubic foot per minute (CFM). The aerosol droplets contain 1,700 to 3,000 colony-forming units (CFU) each and have a mean particle size (MPS) of $3.0 \pm 0.3 \mu\text{m}$, which permits reported filtration efficiencies up to more than 99.9 percent.⁶¹

Nelson also developed a higher concentration bacterial challenge for housed filters, equal to or greater than 1×10^6 CFU for permitting its claim of efficiency measurements up to more than 99.9999 percent.

Nelson's **Viral Filtration Efficiency (VFE)** test follows the same BFE test method but uses the bacteriophage phiX174, a virus that infects bacteria. The aerosol droplets, with MPS of $3.0 \pm 0.3 \mu\text{m}$, contain 1,100 to 3,300 plaque-forming units (PFU) of the virus for testing efficiencies up to more than 99.9 percent, and at equal or greater than 1×10^6 PFU for evaluated efficiencies claims of up to more than 99.9999 percent.

A limitation with these methods is that the particle size is not only 10 times larger than MPPS but also is 1,000 times greater in mass and easily subject to inertial impact filtration. While such tests consequently can assert significant efficiencies, the claims may overestimate the filter function against far smaller particles and pathogens.^{62,63}

Moreover, aerosolization increases the number of particles that can challenge a filter. For example, a challenge can use 100,000 aerosols. Subsequently, a manufacturer could claim, on finding that none pass the filter, that the filter has a 99.999 percent efficiency. However, "there are simply more microorganisms contained in the same 3.0- μm carrier droplets; the presence of

these extra microbes does not change the filter's ability to capture these relatively large carrier droplets."⁶⁴

ISO

International Organization for Standardization (ISO) established voluntary testing guidance for breathing system filters for anesthetic and respiratory use in 2003, with revisions in 2014.⁶⁵ This test has several distinct aspects from selection of challenge particulate to controls.

The test uses as a challenge an aerosol of "short-term airborne sodium chloride" particles with a median diameter of $0.3 \mu\text{m}$, much closer to the size of actual virions. After aerosolization but prior to filtration, the particles pass through an electrostatic neutralizer to reduce any electrostatic charges. The test also involves using a new filter and one that was humidified for 24 hours or for longer, depending on the filter's duration of use as defined by the manufacturer. Additionally, the test counts MPPS at the start and after the filter's duration of use. As a result, this "salt test" can accurately calculate the "minimum effectiveness of the filter when challenged with a worst-case microbial or pathogenic challenge."⁶⁶

The importance of testing selection and controls is underscored by a 2004 survey of 44 filters, 16 mechanical and 28 electrostatic, whose manufacturers claimed were high-efficiency. While 16 filters had undergone independent testing, 28 had not. Also, only eight had 24-hour preconditioning prior to testing to simulate clinical conditions of pressure, temperature and humidity. Only two of the six HME filters tested with *Mycobacterium tuberculosis* and HCV underwent 24-hour testing. Moreover, some filtration results given in 12 commercial brochures exceeded that reported in the accompanying technical documents.⁶⁷

Clinical Practice

RECOMMENDED MINIMUM EFFICIENCY

To prevent the spread of TB in breathing circuits, the CDC recommends filters with a 95 percent or greater efficiency for MPPS particles of 0.3 μm in both the unloaded and loaded states at the ventilator's maximum flow rate.⁶⁸ To prevent SARS transmission, B/V filters with 99.97 percent efficiency are recommended.⁶⁹

In testing, efficacy ratings of 99.9999 percent for a HEPA or B/V filter are better than ratings of 99.97 percent. However, in clinical settings, the use of filtration can differ from that anticipated by performance in controlled lab tests.

Clinical reports have been equivocal as to whether the decrease in bacterial and viral contamination due to filtration of breathing circuits results in decreases of infections, such as post-operative infections or ventilator-associated pneumonia (VAP).^{70,71,72} Therefore, the efficacy of filters remains incompletely proven without clinical application evidence of filtration performance and related reduction in the incidence of infectious transmissions. Such efficacy requires a validated standard test that can be uniformly applied, which does not currently exist.

EXTENDED USE

The COVID-19 pandemic has created a situation in which many healthcare facilities find that supplies are limited, including filters used in breathing circuits. This circumstance raises questions about how long filters might be used without reducing their efficacy.

Risks

Filters have been safely used in breathing circuits for more than 24 hours, but it is essential to know for what applications such durations were employed. Investigations of HME filters have found that use for three days, in comparison to 24 hours, in an intensive care setting did not diminish efficacy, nor increase bacterial

colonization or hospital-acquired pneumonia.⁷³ Additional studies have documented HME filters used continuously retained efficacy for seven days of patient care.^{74,75,76,77}

In determining how long to use circuit filters for critical care circuitry, practitioners should consider several risks, including occlusion and inhalation of the patient's exhaled carbon dioxide (EtCO_2).

Occlusion risk

Tracheal secretions or circuit condensation can both contribute to an HME filter reaching its maximum moisture saturation, creating notable air resistance to a ventilator circuit. When saturated, an HME filter can resist "both inspiration and expiration presenting as high peak airway pressures and incomplete exhalation."⁷⁸

Of note, in unassisted breathing, a patient's normal ventilation of seven LPM-1 has a humidity of 32 grams (g)/ m^{-3} at temperatures of 32 to 34°C. When breathing circuits are used in intensive care, the target humidity is 30g/ m^{-3} at a minimum of 30°C, and for anesthetic use, 20 g/ m^{-3} .⁷⁹

If humidity is inadequate during critical care, mucus can thicken and inhibit mucociliary transport to a standstill and cause cell damage and decrease the function of both the patient's respiratory system and the external equipment.⁸⁰ Because breathing circuits for surgical anesthesia are used for shorter durations, lower humidity levels may be tolerated. In fact, anesthesia ventilators that employ circle systems are self-humidifying, as exhaled CO_2 reacts with an absorber such as soda lime to create water vapor and, therefore, HME filters are not required for moisturizing.⁸¹

HME filters blocked with moisture can increase baseline airway pressure and risk of tracheal tube occlusion.^{82,83} Clogged HME filters also can cause progressive declines in tidal volumes to the point of patient hypoventilation, hypercapnia or

desaturation, or in the case of severe obstruction, atelectasis or pneumothorax.⁸⁴ Additionally, increased resistance may contribute to inaccurate assessment of the system mechanics, inappropriate medical therapy, such as the use of bronchodilators, or difficulty in weaning a patient from ventilation.⁸⁵

If a saturated HME filter creates an obstruction, the circuit pressure will rise to the ventilator's limit, triggering an alarm. Typically, the ventilator pressure limit should be 30 to 40 cm H₂O.⁸⁶ The risk associated with HME filter-related occlusions may be reduced by placing the filter at a level higher than a patient's lungs and keeping the filter in a vertical orientation.⁸⁷ Moreover, "an increase in pressure-support ventilation (5±10 cm H₂O) might compensate for the increased work of breathing" with the use of HME filters.⁸⁸

EtCO₂ Risk

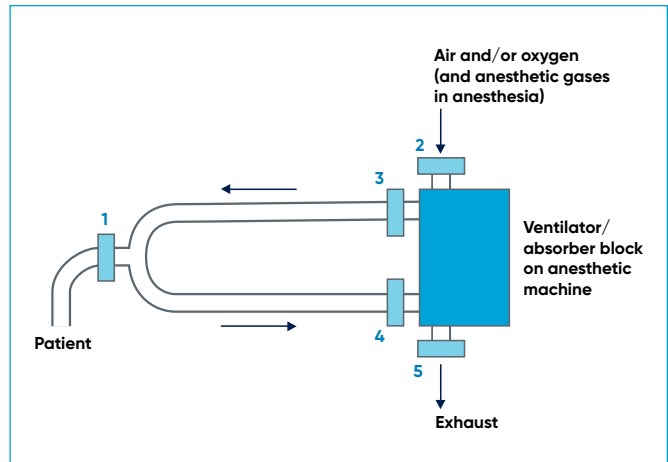
HME filters extend the dead space of the breathing circuit, which can create the risk of inhalation of more of the patient's CO₂. On the machine side, the gas mix includes fresh gas with a lower partial pressure of CO₂, while the patient's side can become purely expired gas. As a result, the patient is at risk for increased spontaneous respiratory rate, arterial partial pressure of CO₂ and intracranial pressure.⁸⁹

FILTER PLACEMENT

A filter placed at the patient connection port can help protect the system and the patient and reduce moisture loss.⁹⁰ But depending on the intended use of a circuit, the type and placement of filters vary.

- **For intensive care settings**, the patient connect port can have either an HME alone or with a pleated or electrostatic filter. The air inlet and inspiratory port can use either pleated or electrostatic filters. The expiratory port and exhaust port can use pleated filters or if an HME is used at the patient connection port, an electrostatic filter.

- **For anesthesia use** with a low fresh-gas flow circle system, either an HME with a pleated filter or a single-use HME alone should be used at the patient connection port, along with pleated filters at both the inspiratory and expiratory ports.



"Possible placements of breathing system filters. 1: at patient connection port; 2: on the air inlet port; 3: on the inspiratory port; 4: on the expiratory port; 5: on the exhaust port."¹⁰⁵

CONSERVING FILTERS

Ideally, at least two filters should be changed with every patient use: in the expiratory port limb at the connection to the machine and at the Wye connector between the circuit and the patient. These locations protect against contamination of the machine and thus the potential for cross-contamination or transmission of pathogens when sampling gases for analysis.^{91,92}

The Anesthesia Patient Safety Foundation (APSF) and the American Society of Anesthesiologists (ASA) collaborated on information that is helpful to consider if the supply of filters is limited.⁹³

"How often the filters need to be changed will depend upon the type of filter and clinical use. Filters mounted at the airway are susceptible to progressive occlusion by secretions and may need to be changed if resistance to flow and airway pressures become too high. Filters at the expiratory limb are less likely to need replacement due to occlusion. Manufacturers typically have recommended

maximum intervals for changing filters. These recommendations should be observed unless shortages make replacement difficult or impossible, in which case continuing to use the filter is better than nothing. As long as the filter is not soiled, viral filtration effectiveness should be maintained.

- **The airway mounted filter** will need to be changed between every patient. The patient side of the filter contains whatever particles the patient exhaled, including virus if present.
- **The expiratory limb filter** seems like an option to leave in place between patients if the filter supply is constrained due to the directional flow of gas away from the patient.”

If a breathing circuit must be reused, evidence suggests a limitation of 24-hour duration. Use for more extended periods results in bacterial contamination and increased risk for VAP, as documented in a study of the continuous use of single HME filters, placed at the Wye-piece of circuits, and examined at seven cumulative 2-hour intervals from 24 to 168 hours.⁹⁴

Recommendation: Filters at the Wye connector must be discarded after single-patient use and the expiratory filter should be discarded if it becomes saturated to avoid increased resistance.

Are Filters Effective Against SARS-CoV-2?

As of the beginning of May 2020, no data exist examining the efficacy of breathing circuit filters in preventing SARS-CoV-2 transmission to patients or healthcare workers. Such an evaluation would require using live virus, and has yet to be concluded.

While the use of filters in a breathing circuit decreases viral transmission, the minimum specifications for efficacy to protect against SARS-CoV-2 passage are unestablished. The size of a single SARS-CoV-2 virion is 0.06 to 0.14 μm ,⁹⁵ and carrier particles range in size from 0.25 μm to more than 4 μm ,^{96,97} but could be as large as 10 μm based on data of known infectious respiratory droplets.⁹⁸

No evidence supports an increased incidence of infection transmission when comparing different breathing circuit filters. Many hurdles exist for such transmission to occur: active virus would need to travel through the filters and the caustic environment of the CO₂ absorbent, then survive the low humidity of fresh gas entering the circuit, and traverse the pathways of the inspiratory side of the ventilator and breathing circuit.

Wherever possible, clinicians should be vigilant in using high efficacy filters and good infection control practices.

Acknowledgment: Marion E. Glick helped in preparation of this manuscript.

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