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Filtration of breathing gases

By Joe Hylton, BSRT, RRT-NPS, FAARC

Filtration of contaminated breathing gases is a necessary measure in mechanical ventilation. There are two types of filters available for filtration of breathing gases: mechanical filters and electrostatic filters. Filter efficiency can be established through a number of means, the most stringent being the High Efficiency Particulate Air (HEPA) test. While a variety of HEPA-grade filters are available, single-layer media and electrostatic filters are those commonly used in breathing circuits and heat and moisture exchange filters. Filters are generally used in equipment where bacterial contamination can occur, such as breathing tubes, mechanical ventilators and anesthesia circuits and nebulizers. Use of these filters can potentially minimize the risk of infection and cross-contamination to patients, caregivers and visitors in the critical care setting. For optimal filter function, attention must be paid to factors such as humidity, airflow rate, filter drying or obstruction, decreased performance with anesthetic gases, and the possible buildup of toxic gases in closed anesthesia circuits. The clinical benefits of filtering exhaled gases are many, the most important of which is the protection of patients, healthcare workers, and visitors from nosocomial infections. Effective filtering may also reduce or prevent asthma episodes in healthcare workers, although more data is needed. More studies need to be performed to demonstrate the effectiveness of filters, through bacteriological monitoring and epidemiological monitoring.

Panel Discussion: Filtration of breathing gases during mechanical ventilation

Moderator: *Ruben Restrepo, MD, RRT, FAARC*

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Filtration of both inspiratory and expiratory gases through competent filters is of critical importance in the clinical setting. Patients and caregivers are constantly exposed to pathogens in the form of infectious aerosols that may also contaminate any compressed air prior to exiting the internal parts of the ventilator during a mechanical breath. In this issue our panel of experts discusses the mechanisms of filtration and the types of bacterial/viral filters and summarizes some of the most important clinical applications of devices designed to filter breathing gases during mechanical ventilation.

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Filtration of Breathing Gases

By Joe Hylton, BSRT, RRT-NPS, FAARC

Contaminated breathing gases have been identified as a serious problem in areas where mechanical ventilation occurs. The operating room (OR), intensive care unit (ICU), emergency department (ED), post-anesthesia care unit (PACU) and physician clinics are areas that utilize therapies that produce aerosols. Contaminated gases can pose a problem to the patient as well as caregivers, so efforts to limit contamination are put into place. Sterilization of masks, connectors and tubes from breathing machines; and the use of single-patient disposable circuits, tubes, connectors and masks have been recommended as standard infection control practices in the United States.^{1,2}

Filtration of breathing gases for the purpose of minimizing cross-contamination is another process undergoing considerable research. There is a growing concern about potential health hazards posed to emergency and healthcare personnel with inhalation of biologically hazardous particles.³ The exhaled gas of mechanically ventilated patients may contain a host of hazardous particles, including bronchodilators, antibiotics, steroids, antiviral agents, antiprotozoal agents and mucolytic agents, as well as potentially hazardous bacterial and viral particles, all of which pose a potential threat to caregivers, patients and visitors.⁴ Bioterrorism threats also present a growing concern to emergency and healthcare personnel.⁵

Filtration and Mechanisms of Filtration

Filtration is defined as “the act or process of filtering, especially the process of passing a liquid or gas through a filter in order to remove solid particles.”⁶ Filters are used to prevent undesirable particles being delivered to patients through inspired gases and to potentially remove

particles from exhaled gases. Exhaled gas from critically ill patients with infections may contain bacterial or viral pathogens that can potentially be transmitted to other patients, healthcare workers or hospital visitors.

Filter material is commonly comprised of a formed, non-woven wad or sheet, which consists of fibers.⁷ Particles are captured by the filter material as gas flow follows a tortuous pathway created by the interconnected void spaces within the structure of the filter. As the gas stream moves through the filter structure, particles are deposited on the filter material. Removal of particles by filtration can be achieved by 6 mechanisms of action: interception, inertial impaction, gravitational settling, diffusion, electrostatic attraction, or sieving.^{7,8}

Interception

Particles suspended in gas tend to follow the streamline in a flow of gas. If the particle suspended in the gas streamline comes within one particle radius of a filter fiber, the particle will be “intercepted” and adhere to the fiber. Interception works best on particles in the mid-range of size (0.1 - 1.0 mm and larger) that are not large enough to have significant inertia and not small enough to diffuse within the gas stream.^{7,9}

Inertial Impaction

Particles in a gas stream that possess significant mass are not always able to follow the gas streamline around a filter fiber, due to their inertia. They are not able to respond to the changes in the gas streamline near the fiber and will continue on their original path and physically hit the filter fiber, even though the gas streamline may be more than one particle radius from the fiber. This process defines the mechanism of inertial impaction. Inertial impaction usually affects particles that are 0.3 – 1.0 mm in size.⁷⁻¹⁰

Gravitational Settling

Particles that possess mass are subjected to the effects of gravity in slow-moving streamlines of gas. These particles will settle due to gravitational forces and may fall onto and adhere to a filter fiber. This principle affects larger particles, usually greater than 10 mm.^{7,8,9,10}

Diffusion

Kinetic activity of particles plays an important role in filtration. All particles are continually in random motion, colliding with each other and their environment. This “zigzagging” random motion is defined as Brownian motion or movement. In gas filtration, Brownian movement of particles with gas molecules alters the particles’ trajectory around the filter fibers. Brownian movement more profoundly affects particle movement as the particle size becomes smaller, especially for particle sizes less than 0.1 mm. The smaller the particle and the slower the gas streamline, the better chance the particle has of impacting and adhering to a filter fiber.⁷⁻¹⁰

Electrostatic Attraction

Filter material can be electrostatically charged during the manufacturing process to heighten particle capture. There are three potential mechanisms of electrostatic capture: (1) charged particles in the streamline can be attracted to filter fibers with an opposite charge, (2) neutral particles in the streamline can be attracted to charged filter fiber as the electrical field on the fiber creates a dipole in the particle (positive and negative charges on opposite sides of the particle), or (3) charged particles can be attracted to neutral filter fibers by inducing forces on the fibers.⁷

Sieving

Sieving occurs in filtration when particles are physically unable to pass through openings on the filter structure and become trapped, due to their larger size.⁷

Types of Bacterial/Viral Filters

Two types of bacterial/viral filters are available for filtration of breathing gases. Mechanical filters physically stop particles because of the small pores in the filter design; electrostatic filters are electrostatically charged to attract and capture particles.

cally charged, thus attracting and capturing charged particles.¹¹

Mechanical filters

Mechanical filters usually consist of a sheet of densely packed glass fibers that have been resin-bonded. This sheet provides a high resistance to gas flow per unit area due to the dense packing of the fibers. To decrease the resistance to gas flow to an acceptable level, a glass fiber sheet with a large surface area is utilized. The sheet is pleated to maintain a large surface area in a smaller package, also reducing deadspace in the housing. The fiber sheet is hydrophobic, in an effort to minimize water absorption under normal operating conditions.⁷

Electrostatic filters

Electrostatic filters, unlike glass fiber filters, utilize a flat layer of fiber material as a barrier. The fiber density for electrostatic filters is lower than that of glass fiber filters, thus providing less resistance to gas flow per unit area. The filtration performance of electrostatic filters is enhanced by implementing a fiber material that is electrically charged. This electrically charged material attracts and binds to any particle that passes through it. The filter material does not need to be pleated to increase surface area, because of its lower resistance to gas flow and electrostatic attraction of particles. Because of their design, electrostatic filters provide a lower deadspace volume.⁷

Electrostatic filters exist in two types: tribocharged filters and fibrillated filters. Tribocharged filters are constructed of two different types of materials, mod-acrylic and polypropylene fibers. During the manufacturing process, these fibers are rubbed together, creating a positively and negatively charged fiber; the tribocharged fibers are then constructed into a nonwoven felt, providing a filter material. Fibrillated filters are constructed of a polypropylene sheet. An electrostatic charge is applied to the sheet by corona charging, implementing a point electrode that emits ions to one side of the sheet; an opposite charge is then applied to the opposite side of the sheet. Once electrostatically charged, the sheet of material is of-

Type	Filter Class	Efficiency	Penetration
HEPA	H 10	85%	15%
HEPA	H 11	95%	5%
HEPA	H 12	99.5%	0.5%
HEPA	H 13	99.95%	0.05%
HEPA	H 14	99.995%	0.005%

Table 1: HEPA filter rating scale. (from ref. 14)

ten referred to as an electret. It is then split into fibers by implementation of a process called fibrillation, then constructed into a nonwoven filter wad.⁷

Efficiency, Specifications and Clinical Relevance

Many different methods are utilized to measure filter efficiency. Ideally, the measurements should be performed in an environment that most accurately resembles the clinical arena. A method that is commonly implemented in filter efficiency is to expose the filter to a nebulized bacterial/viral suspension and measure the number of organisms that pass through the filter. A nebulized suspension of sodium chloride has also been utilized for measuring filter efficiency.¹² Filter efficiency is often expressed as percent efficiency. Specifically, this expression defines the ratio of upstream particle concentration compared to the downstream concentration of particles after passing through the filter. It is important to recognize that efficiency specifications are useless, without also stating the particle size and gas flow rate utilized in testing.^{7,9,12}

Another method of establishing filter efficiency is the High Efficiency Particulate Air test, which is considered to be the most stringent of efficiency tests.

HEPA filter technology was developed during World War II during the Manhattan Project, in an effort to protect personnel against chemical and biological warfare agents. HEPA filters are classified into true HEPA filters and HEPA-type filters, with a subgroup of HEPA filters called Ultra Low Penetration Air (ULPA) filters. ULPA-type filters offer increased filtration, but the resistance level is too high for medical breathing devices. HEPA filters are constructed of glass fiber mate-

rials, which are pleated to increase their surface area and minimize deadspace.¹² Particle filtration is achieved by inertial impaction for particles $> 0.3 \mu$ and smaller particles are trapped by Brownian movement. Particles of 0.3μ —referred to as MPPS (most penetrating particle size)—are the most difficult to capture by filtration because they are the least affected by inertial impaction, interception and Brownian movement.

There are two accepted testing mechanisms for HEPA certification: the British BS3928 Sodium Flame method and the USA Hot DOP (di-octyl-phthalate) method.¹² The British BS3928 test utilizes sodium chloride to measure filter efficiency; the particle size for this test is smaller than the USA Hot DOP test, with a median diameter of 0.07μ . The USA Hot DOP test utilizes a particle size with a mean diameter of 0.3μ .^{12,13}

HEPA filters are rated based on the percentages of particles of a specific size that are filtered out. As discussed above, 0.3μ is the particle size most difficult to capture by filtration. A filter must trap particles down to 0.3μ to be classified as a HEPA filter. However, it is important to note that HEPA is a rating scale that has different percentages of filtration. For example, a H10 HEPA filter will capture 85% of all particles; a H14 HEPA filter will capture 99.995% of all particles. (see figure 1.) The table above demonstrates the entire HEPA filter rating scale.¹⁴

Clinical Applications

Bacterial filters have many clinical applications in the healthcare arena. Filters are utilized in pulmonary function testing, in hospital wards and physician offices, in the ORs for anesthesia applications and in the ICUs for respiratory care applications.



Figure 1. Gilbeck ISO-Gard Filters from Teleflex are classified as HEPA Class 13 (Courtesy Teleflex)

Respiratory and Anesthesia Applications

Therapies and interventions that come into direct contact with the upper airway will almost invariably become contaminated with microorganisms. Breathing tubes, mechanical ventilation/anaesthesia circuits and nebulizers that deliver aerosolized medications are examples of interventions that can harbor pathogen collection and growth.

Filters may be used on nebulizers to protect caregivers from microbes and potentially hazardous aerosolized pharmaceutical agents exhaled from sick patients. Pentamidine, an antimicrobial agent, is delivered through a specific nebulizer, the Acorn II® (Vital Signs; Totowa, NJ), which is engineered with an expiratory filter to protect caregivers against incidental exposure.⁴ Filters are incorporated into pulmonary function testing devices to protect against cross-contamination and equipment malfunction,^{15,16} and have been shown to prevent natural rubber latex sensitization in animal models.¹⁷ Filters can be placed in as many as 3 spots on a mechanical ventilation circuit to provide protection. To prevent potential contamination, a filter may be placed on the inspiratory outlet of the mechanical ventilator and then connected to the inspiratory limb of the ventilator circuit.

Contamination via medical gases is the least susceptible pathway,²⁰ however filters may be placed between the circuit wye (Y) and the endotracheal tube. This filter is almost always a combination bacterial filter/heat moisture exchanger. Bacterial formation can occur inside the endotracheal tube, creating a biofilm that allows potentially rapid bacterial growth.

Bacterial particles can be transported from the biofilm into the breathing circuit, promoting contamination of the ventilator circuit.^{21,22}

Anesthesia applications include placing a combination bacterial filter/HME at the patient wye to prevent contamination of the breathing circuit, reservoir bag, bellows and tubing.²³ A filter placed between the wye and endotracheal tube may limit contamination of the ventilator circuit. It is most often placed on the expiratory outlet connection of the ventilator and then connected to the expiratory limb of the ventilator circuit.

There are reports of ventilator circuits serving as a reservoir of pathogens that could potentially infect other patients, caregivers and visitors.^{5,24} Intermittent Positive Pressure Breathing (IPPB) equipment has been shown to deposit specific organisms as far as 32 feet from the exhalation valve.²⁵ Ribavirin, an antiviral agent, is delivered through a specific nebulizer, the small particle aerosol generator (SPAG). Crystallization of ribavirin in the exhalation limb of a mechanical ventilator circuit could possibly cause malfunctions of sensors, transducers and valves that are critical to ventilator function and patient safety.⁴ Placement of a filter on the expiratory limb may prevent contamination of the ventilator exhalation valve, as well as potentially minimizing ICU staff and visitor exposure to contaminated exhaled gases from patients.

Bacteriological Assessments

Multiple bacteria have been identified in the inspiratory and expiratory limbs of ventilator circuits, as well as in mechanical ventilator heated humidifiers. *Acinetobacter calcoaceticus*, *Pseudomonas maltophilia*, *Pseudomonas aeruginosa*, *Flavobacterium meningosepticum*, *Klebsiella pneumoniae*, *Proteus mirabilis*, *Enterobacter cloacae*, *Citrobacter diversus*, *Enterobacter agglomerans*, *Candida albicans*, *Enterobacter cloacae*, *Proteus* species and *Streptococcus* species have all been isolated from mechanical ventilator circuits.^{4,24} The respiratory tract is the most common route of entry for pathogens into the hu-

man body, with billions of particles being inhaled every day.^{25,26} The location of deposition of these particles in the lung depends on the physical principles of sedimentation, impaction and diffusion.²⁷ All particles smaller than 10 μm in diameter have the potential for being biologically active in susceptible individuals, from a toxicological standpoint.²⁷ Most particles <8 μm in diameter will impact above the level of the larynx and will not reach the lung. Particles in the range of 1-8 μm in diameter may deposit in the large and small airways, as well as the alveoli.²⁸ The particle size range that provides for the greatest alveolar deposition is the 1-2 μm diameter size.^{29,30} Mechanical ventilation circuits in the intensive care setting are “open” circuits, releasing exhaled gas into the ICU atmosphere. This creates a potential pathway for nosocomial infections among patients. Caregivers and visitors are at a potential risk from particles in exhaled gases. In addition to active bacterial and viral particles, exhaled gas from critically ill mechanically ventilated patients can contain products of cellular degradation from specific dead gram-negative organisms that have been identified as triggers of reactive airway disease in healthy subjects.⁴ Use of filters can potentially minimize the risk of infection and cross contamination to patients, caregivers and visitors in the critical care setting.

Hazards, Maintenance and Monitoring

The use of breathing system filters to filter exhaled gases in the hospital environment can potentially minimize risk of nosocomial infections and provide protection to healthcare staff and visitors. The routine use of filters, however, does come with risks and hazards. There are several factors that may affect filter performance.

Humidity has been identified as a factor that may influence filter performance, although the effects are not well understood. For mechanical filters, one study demonstrated no effects on filtration with varying levels of relative humidity. In contrast, another group of investigators dem-

onstrated improved filter efficiency with increased levels of relative humidity. In contrast, studies investigating the effects of humidity on electrets (charged) filters demonstrated a decreased level of performance as relative humidity increased.²⁶

Airflow rate can profoundly affect filter performance. While interception increases at higher flow rates, diffusion and electrostatic forces are decreased, resulting in an overall decrease in filter performance. It is felt that increased velocity of particles with higher flow rates increases particle penetration, due to shorter residence time spent in the filter.²⁶

Anesthetic gases demonstrate decreased performance in pediatric breathing system filters. Desflurane was shown to decrease filtration performance and allow increased particle penetration in 3 of 5 filters tested. Tribocharged filters were significantly more affected by desflurane than fibrillated filters. Investigators were not able to explain why desflurane exerted such an adverse effect on tribocharged filters.³¹

Filters may be very harmful in anesthesia applications as well in that they may promote buildup of harmful gases in closed anesthesia circuits. Carbon dioxide adsorbents degrade volatile anesthetic gases to compounds that are toxic, carbon monoxide being among the most worrisome.⁵ Drying and desiccation of the adsorbent has been identified as a root cause of decreased function, which may lead to carbon monoxide production.^{5,7} Filters, especially HME filters that are placed before the adsorbent, can retain humidity on the patient side of the filter and leave dry the gas on the adsorbent side of the filter. This will not allow rehydration of the adsorbent granules, promoting desiccation and carbon monoxide production secondary to degradation of volatile anesthetics.

Partial or total obstruction of filters is inevitable when certain circumstances are present; this can occur suddenly or over time.⁵ Nebulized medications, secretions and pulmonary edema have been identified as potential causes of filter obstruction.^{5,7} Any obstruction will increase

resistance through the filter, potentially allowing for decreased minute ventilation, air trapping and pneumothorax.⁵

For transport ventilators requiring battery power, Blakeman et al. demonstrated in a lab environment that a combined chemical, biological, radiological and nuclear filter did not provide significant resistance to airflow to affect battery duration.³²

Dead space volume of breathing filters is a concern if the filter is placed between the ET tube and the circuit wye. The filter/HME dead space should be no more than 1/5 of the delivered tidal volume, to minimize CO₂ retention.⁷

Clinical Benefits

The clinical benefit of filtering exhaled gases in healthcare is wide in scope. Protection of patients from nosocomial infections, protection of respiratory equipment, and protection of the healthcare team and hospital visitors are areas in which filters may have the most profound impact.

Nosocomial/Ventilator Associated Pneumonia

Nosocomial infections, especially bacterial pneumonia, are a recognized complication from long-term mechanical ventilation. The National Nosocomial Infection Surveillance survey demonstrated that nosocomial pneumonia is the second leading cause of hospital-acquired infection. Intubation and mechanical ventilation increase this risk through various mechanisms, including inhalation of exogenous organisms via contaminated air and gases. Contamination of air and gases can occur from contaminated breathing equipment such as humidifiers, nebulizers, ventilator and anesthesia circuits. Contaminated condensate in mechanical ventilator circuits has the ability to contaminate the patient as well as the potential to contaminate other patients.^{33,34} The use of breathing filters may be effective in minimizing or preventing contamination of equipment, patients and caregivers.

The data for effectiveness of filters is mixed. In anesthesia applications, combined HME/bacterial filters were shown

to be effective in reducing colonization or infection by *Pseudomonas aeruginosa* in mechanically ventilated patients.³⁵ However, a prospective, randomized trial on the effectiveness of sterile anesthesia breathing circuits with bacterial filters demonstrated no significant difference in rates of pulmonary infections between groups of patients who had undergone surgical procedures with and without bacterial filters.³⁶ In a lab environment study of 6 HME/filters, Scott et al. demonstrated free passage of *Candida albicans* and coagulase-negative *staphylococci* and concluded that large organisms may pass across moist breathing system filters found in clinical practice.³⁷ Aranha-Creado et al. demonstrated efficient removal of *Mycobacterium* species with 3 filters, demonstrating > 99.99% to > 99.999% efficiency.³⁸

The data in intensive care units are mixed. Kirton et al. reported a reduction in late onset hospital-acquired ventilator-associated pneumonia (VAP), reduced ICU stay and a decreased equipment cost, but no reduction in early-onset, community-acquired VAP with HME filters, when compared to heated wire humidifiers.³⁹ In a meta-analysis of 8 randomized controlled trials comparing HME filters to heated wire humidifiers, Kola et al. concluded that HME filters demonstrated a significant reduction in VAP, especially in patients requiring mechanical ventilation for 7 days or longer.⁴⁰ In contrast, Lacherade et al. demonstrated in a randomized controlled trial that there was no significant difference on the incidence of VAP with HME filters or heated humidifiers.⁴¹ Lorente et al., in a prospective randomized study, concluded that bacterial filters in ventilator circuits neither reduced the prevalence of respiratory infections nor decreased exogenous infectious events, negating their use in mechanical ventilation.⁴²

Healthcare Providers and Asthma

Inhalation of hazardous particles in the healthcare setting may also pose a detrimental effect to caregivers. Occupational asthma has been identified in the healthcare industry, occurring mostly

in pharmaceutical manufacturing facilities and animal research laboratories.⁴³ In 1989, Kern and Frumkin screened respiratory therapists, physical therapists and a small sample of radiological technologists in Rhode Island.⁴³ Their research identified an excess of asthma in respiratory therapists that developed after entry into the profession. Pechter et al. assessed work-related asthma cases in California, Massachusetts, Michigan, and New Jersey from 1993 to 1997.⁴⁴ They demonstrated that healthcare workers made up 8% of the workforce in the states screened but accounted for 16% of work-related asthma cases. They identified cleaning products, latex and poor air quality as the most commonly identified exposures. Delclos et al. sampled 3,650 physicians, nurses, occupational therapists and respiratory therapists in Texas in 2003, identifying an approximate 2-fold increased likelihood of asthma after entry into a healthcare profession that involved instrument cleaning/disinfection, general cleaning products, use of powdered gloves and administration of aerosolized medications.^{45,46} The literature is absent of any data demonstrating a reduction in healthcare-associated asthma with the use of breathing circuit filters.

Conclusion

Ideally, breathing system filters should provide an effective barrier between the patient and the ventilator, protecting the patient, equipment and the caregivers. Filtration of both inhaled and exhaled gases is thought to provide potential benefits to patients and caregivers. However, the supportive data for the effectiveness of filters in the prevention of VAP are minimal. No supportive data exists for the effectiveness of filters in the prevention of healthcare associated asthma. More studies need to be performed to demonstrate the effectiveness of filters, through bacteriological monitoring and epidemiological monitoring.

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Panel Discussion: Filtration of Breathing Gases during Mechanical Ventilation

Moderator:

Ruben Restrepo, MD, RRT, FAARC

Panelists:

John Davies, MA, RRT, FAARC

Max Eskelson, MsCHA, RRT

Jack Fried, MA, RRT

Filtration of both inspiratory and expiratory gases through competent filters is of critical importance in the clinical setting. Patients and caregivers are constantly exposed to pathogens in the form of infectious aerosol that may also contaminate any compressed air prior to exiting the internal parts of the ventilator during a mechanical breath. Furthermore, a long list of aerosolized medications that includes bronchodilators, corticosteroids, anti-infectives, and antimicrobials are often administered to patients undergoing mechanical ventilation. Filtration of breathing gases has been designed to eliminate any potential source of nosocomial infections and minimize the incidental exposure of caregivers to any aerosolized medications. The Centers for Disease Control and Prevention has clearly established standards to classify a filter as a high-efficiency particulate aerosol (HEPA) device. While a variety of HEPA-grade filters are available, single layer media and electrostatic filters

are those commonly used in breathing circuits and heat and moisture exchange filters (HMEFs). These filters may not provide the efficiency offered by HEPA-grade devices. However, it is important to note that the both the filter media and the procedures used to test HEPA filters are different than those used to test other filters, such as electrostatic filters. Therefore, manufacturers' claims of 99.9% efficiency with regard to bacteria and viruses must be evaluated according to the test methodology. In this issue, our panel of experts discusses the mechanisms of filtration and the types of bacterial/viral filters and summarizes some of the most important clinical applications of devices designed to filter breathing gases during mechanical ventilation.

What does the Centers for Disease Control (CDC) recommend for standard filtration of breathing gases?

Davies: Generally, there are 2 sites on the ventilator circuit that bacterial filters can be placed to minimize cross-contamination; one of the sites is on the inspiratory limb between the ventilator and the patient. Bacteria/viral filters interposed between the ventilator and the inspiratory circuit can serve to eliminate contaminants from the driving gas and prevent retrograde contamination of the machine by the patient. This may even be of more importance in ventilators that draw in room air as opposed to using a

50-psi air source. However, the CDC does not consider the internal machinery of the mechanical ventilator to be an important source of bacterial contamination of inhaled gas.¹ Also, bacterial filters with high resistance may affect the delivery of the inspired gas. While the CDC recommends that a bacteria filter not be placed between the humidifier reservoir and the inspiratory limb of the circuit, it does not provide a recommendation for the placement of a filter on the expiratory limb near the exhalation valve. While this practice has the potential of preventing cross-contamination of the patient's surrounding environment, bacterial filters on the expiratory limb have not been shown to reduce ventilator-associated pneumonia (VAP).

Fried: In line with John Davies's comments, it is important to emphasize that the CDC's Guidelines for the Prevention of Nosocomial Pneumonia make no specific recommendations for filtration of gases delivered by medical devices, due to the lack of evidence linking use of filtration to reduction of VAP. Other regulatory bodies regulate the make up and procedures for filling oxygen cylinders and for construction of medical gas piping systems to prevent the contamination of the gas, but none specify or mandate requirements for filters on medical equipment.

Eskelson: I, too, am unaware of any specific guidelines by the CDC. When utilizing filters, we must factor in the resistance these filters cause in the system, and how they may disrupt the flow of gas from the mechanical ventilator.

Restrepo: Almost 20 years ago, the CDC created guidelines to protect caregivers from contracting tuberculosis. The minimum standard established for high-efficiency particulate aerosol (HEPA) masks was defined as a capability to filter 99.97% of particles with a diameter of 0.3 μm .^{1,2} When patients are tracheally intubated and mechanically ventilated, perhaps the same level of efficiency should be expected when filtering inspired and ex-

haled gases through the ventilator circuit. However, the performance of multiple or even single-patient-use disposable incorporated within the expiratory circuit of various commercial ventilators has been seriously questioned in the past. There is little evidence to support their performance at HEPA-grade filtration levels or that they truly filter viruses and bacteria. It has been suggested that these filters have been tested with nebulizers able to produce aerosol particles with diameter of 3 μm , or even larger.^{3,4} Regardless of the efficiency of the filter, the healthcare provider needs to remember that a good filter is no replacement for routine use of universal precautions.

What factors make a bacterial/viral filter competent?

Davies: The CDC has recommended that health care providers exposed to patients with tuberculosis (TB) use masks that have the ability to filter particles as small as 0.3 μm with an efficiency of > 95%.¹ Since bacteria and viruses vary in size, this would seem like a reasonable goal for respiratory circuit filters. Interestingly, there appears to be no standard for manufacturer testing of bacteria filters. Many use an inactivated bacterium of a specific size for testing. Different manufacturers use different test bacteria. While most package inserts claim an efficiency >99%, the test particle size is not always clearly defined.

Fried: Standards for rating the effectiveness of filters remains controversial. Ideally, nothing should pass to the patient but the inhaled gas mixture. That, of course, is not possible. The German Society of Anesthesiology and Intensive Care recommends a “filter retention efficiency for airborne particles” to be > 99%. As far as the size of particles is concerned, various authors have made numerous recommendations. Recommendations range from 1.2 μm to 5 μm in diameter, with most in the proximity of 2.5 μm . While most nosocomial pneumonias are bacterial in origin, most viruses are smaller than most bacteria; and viral pneumonias are more

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- Restrepo -

difficult to treat.

Eskelson: Regardless of the filtration device chosen, we need to make sure that we follow basic Post Exposure Prophylaxis (PEP) procedures: gowning, gloving and masking. Hand washing is the most important, and it is the most often missed part of the cycle. As for aerosol size, we all know that healthcare workers are already colonized with a vast array of bacteria. We have an intact upper airway system that will screen out most of them.

Restrepo: Although bacteria residing in the ICU environment are typically in the 0.3 μm diameter range, most commercial filters are tested at droplet sizes near the 3.0 μm size. Some filter media manufacturers report filter efficiency > 99.9% when tested with an aerosol comprised of droplets having a diameter of 0.3 μm .⁵ However, some of this data has not been confirmed outside the manufacturer’s laboratory.⁶ An evaluation of four HMEFs showed an efficiency of viral/bacterial filters > 99.99%.⁷ Although found to be efficient filtering devices, resistance to airflow in the HMEs increased by nebulization of medication. A recent evalua-

tion of HMEFs has confirmed this level of performance in some additional filters.⁸ The US Army Chemical Corps had previously defined competent filters as those with the ability to trap aerosols 3.0 μm or greater. However, some authors have stipulated that filters should be defined as competent only if they filter > 99.99% of particles at least 0.3 μm in diameter.⁹ Filters must be tested with aerosols containing only bacteria, not liquid droplets that increase the particle size and may be easily trapped in the filter. Some additional important features make filters competent. The filter at the breathing circuit should be hydrophobic so bacteria, viruses, and secretions are not simply moved across the filter. Equally important is the fact that at airway pressures exceeding 14 cm H₂O, the filter’s integrity may be compromised, and inadvertent exposure of other patients and healthcare providers to infectious microaerosols is a potential risk.¹⁰

How often are nosocomial infections or aerosol toxicity traced back to the expulsion of microaerosols from the mechanical ventilator to justify the use of breathing filters?

Davies: Many experimental studies verify the capacity of bacterial filters to avoid crossing of microorganisms. However, bacterial filtration in the ventilator circuit has not been demonstrated to reduce VAP. It certainly is a possibility that an infected patient can spew out infectious bacteria from the expiratory limb into the surrounding environment. This was especially true during the SARS outbreak in the early 2000s. That unfortunate scenario prompted resurgence in the use of bacterial filters on the expiratory limb. Should we use them on all patients? Certainly they would add another layer of protection for the healthcare worker. However, some dangers exist in this type of use. First, if the filters become saturated with expiratory limb condensate, resistance to exhalation can increase, leading to a higher work of breathing for the patient as well as potentially dangerous baseline pressure elevations.

Fried: Several studies have shown that radioactive isotopes used to mark ventilator exhaled gases can be found anywhere from 25 to 100 feet away from the ventilator. What is not clear is whether bacteria or viruses in this effluent gas can infect caregivers, visitors or other patients. There is no evidence to support this. There is only the rationalization that if infectious organisms can be carried this far by the ventilator, then surely there is the potential to infect people in the vicinity. The fact is that most hospitals in the United States keep ventilator patients in private ICU or emergency department rooms. This may not be the case in post-anesthesia or post-operative care units or in skilled nursing facilities. Patients undergoing short-term postoperative ventilation to recover from anesthesia tend not to harbor infectious organisms, although you often do not know until it's too late.

Restrepo: Filtration of inspired gases through competent bacterial/viral filters is of critical importance in the intensive care unit where patients are constantly exposed to pathogens in the form of infectious microaerosols. This aerosol may very well contaminate any compressed air¹¹ prior to entering or exiting the internal parts of the ventilator during a mechanical breath and become a potential source of nosocomial infections in the ICU.^{12,13} The limited evidence linking these microaerosols to nosocomial infections should not be interpreted as a reason not to follow the recommendations for adequate filtration of breathing gases during mechanical ventilation. In one report, the efficacy of a breathing filter was evaluated over 5 successive inspiratory cycles of the ventilator. The effluent produced almost half of the organisms previously cultured from each patient.¹⁴ Scott et al. have recently confirmed the passage of microorganisms through breathing filters.¹⁵

Should routine bacteriologic surveillance of filters be implemented?

Davies: To determine trends and help identify outbreaks and other potential

Trends toward increased cases of pneumonia in the ICUs should prompt a reevaluation of the type and efficiency of the bacterial filters being used.

- Davies -

infection control problems, the CDC recommends surveillance for bacterial pneumonia in ICU patients who are at high risk for healthcare-related bacterial pneumonia.¹ I believe it is important to include bacteria filters in this surveillance. Trends toward increased cases of pneumonia in the ICUs should prompt a reevaluation of the type and efficiency of the bacterial filters being used. This could be done as part of the VAP monitoring tool. We tend to take bacterial filters for granted and assume they all function equally. However, this may not be the case, as manufacturer testing varies and different sized test bacteria are used.

Fried: In an ideal world, the answer is an unequivocal "yes". You can certainly argue that there is no other way to know for sure. Unfortunately, medicine is practiced in a world that is far from perfect. In a culture with limited resources and heavy emphasis on cost containment, you have to weigh the expected benefit with the costs. Most filters on the market are relatively efficient and well tested before being mass-produced and introduced to the market. Routine bacteriologic surveillance of filters is certainly not cost-effective, and there is no evidence to show its benefit in either terms of human service or reduction of costs from reduced ventilator associated pneumonia.

Eskelson: No. Filters are certified to filter to a certain particle size. If we must verify them all the time, and if we suspect the manufacturer is wrong, we would have to throw the entire shipment away. When you are paying extra money for the certification and you doubt it, what are you doing buying the filters? If the filters are not living up to their expected quality, then we would be seeing a large number of patients with similar organisms.

Restrepo: Validating performance tests outside manufacturers' laboratories will strengthen the already scarce evidence surrounding filtration of breathing gases and its association with nosocomial infections. Routine bacteriological surveillance may also allow for a better evaluation of the filter performance in the clinical setting. However, I agree with Eskelson's comments with regard to the cost associated with the procurement of filters/HMEFs. It may be a very expensive proposal if a clinical hazard is not well-established. However, if there is a documented risk for infection, failing to follow filtration guidelines will be even more expensive than purchasing the equipment. Again, this may be one more reason to seriously undertake bacteriological surveillance of filters and clearly determine their need.

Do HMEFs prevent VAP?

Davies: Heat and moisture exchangers in combination with a bacterial and viral filter are becoming more widely utilized. While providing passive humidification, the filter component has been shown to reduce the risk of viral and bacterial cross-contamination between patients in general anesthesia.^{16,17,18} In the ICU environment however, HMEFs have not yet been shown to reduce the VAP rate or to alter the contamination of the environment.^{19,20} One must also bear in mind the same issues in regards to affecting the breath delivery as with the bacteria filters alone. There have been reports of increased work of breathing and airway obstruction.^{21,22,23} There is also considerable variability among the different types of

HMEFs especially under wet conditions.²⁴ So, if an institution is considering HMEFs an extensive evaluation should be carried out first. Other considerations include the fact that most HMEFs must be taken out of the circuit to allow nebulized drugs to reach the patient. This would cause a circuit break, possibly leading to microaerosol emission to the environment. HMEFs must also be changed from time to time. The CDC recommends changing the HMEF when it malfunctions or becomes visibly soiled. Routine changes should not be done unless directed by the manufacturer. Careful consideration is needed based on patient status and the use of HMEFs. As they have the potential to increase the number of circuit breaks in relation to active humidity, some patients could decompensate due to de-recruitment from the loss of PEEP.

Eskelson: First, I would like to propose a name change from VAP to “artificial airway acquired pneumonia.” The Scottish Intensive Care Society EBM Group did the only study I know that addressed this question.²⁵ They concluded that HMEFs may prevent VAP. This conclusion does no one any good. So, I thought the conclusion of the study was unwarranted and useless. There are so many variables here. The Scottish paper discusses a heated water humidification system and does not mention heated wire circuits. VAP can result from the patient aspirating water that has collected in the ventilator tubing.

If you are using a heated wire circuit, you do not have that problem. They left out too many important variables to make any meaningful conclusion. HMEFs may help, but they may not. What does that do for us as managers and healthcare professionals?

Restrepo: In theory, placement of the HMEF allows for adequate humidification of inspired gases while preserving bacterial filtration of inspired and exhaled gases. While some studies have suggested that prevention or decreased incidence of nosocomial infections is obtained by plac-

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in the pulmonary laboratory have
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challenges.

- Fried -

ing HMEFs,^{26,27} the topic is still controversial.^{28,29,30}

Does recurrent exposure to microaerosols from mechanical ventilators contribute to reactive airway disease (RAD) of caregivers?

Davies: Caregivers with reactive airway disease can experience an exacerbation from a variety of environmental triggers. Certainly microaerosols from mechanical ventilators have the potential to illicit a reaction in caregivers. Factors that may determine whether or not this occurs may depend on the size of the room, type of microaerosol, and quantity of microaerosol. Use of a bacterial/viral filter in the ventilator circuit can act to minimize the risk of this occurring.

Fried: A review of literature evaluating cause and frequency of reactive airway disease (RAD) in caregivers is inconclusive. Therefore, the answer is probably not, but the risk is there. Given the poor air quality in many areas of the United States and, for that matter, in many other countries, caregivers are subjected to many other contaminants. There are anecdotal reports, many of which are through the professional grapevine, in which a clinician never had asthma until he or she worked in health care. Such stories are common in respiratory therapy circles, but many therapists and physicians in the

pulmonary laboratory have encountered latent asthmatics diagnosed with methacholine challenges. Some patients undergoing these challenges say they have never had asthma and cannot understand why they do now. Others claim they have never had symptoms until they began working for their employer or in their current occupation, or even until they moved to their current residence. It is likely these clinicians have always had slightly reactive airways but were not exposed to the right triggers until they were exposed to nebulizer effluent. However, you can never eliminate any chemical exposure as a cause.

Eskelson: If you have reactive airway disease, anything can trigger it if you are not well-controlled. If you have any kind of reactive airway disease, you will wheeze. That is why patients with reactive airway disease should be pretreated with a bronchodilator prior to receiving certain aerosolized medications. If the caregiver has good control over their disease, aerosols will not be a problem.

The exhaled gas of mechanically ventilated patients may contain a host of hazardous particles, including bronchodilators, antibiotics, steroids, antiviral agents, antiprotozoal agents and mucolytic agents, as well as potentially hazardous bacterial and viral particles, all of which pose a potential threat to caregivers, patients and visitors. It is possible that recurrent exposure to microaerosols emanating from mechanical ventilators contributes to a higher incidence of RAD among caregivers, even in those with no prior history of respiratory symptoms before working in the clinical setting. A couple of studies found that respiratory therapists were more than 4 times as likely to be afflicted with RAD than the control group.^{31,32}

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Questions

- Which of the following have been identified as potentially hazardous particles when inhaled?
 - Antibiotics
 - Steroids
 - Bacterial and viral particles
 - All the above
- The physical principle of Interception works to filter particles $>10\ \mu\text{m}$ in size.
 - True
 - False
- The physical principle of diffusion, or "Brownian movement," affects particle sizes $<0.01\ \mu\text{m}$ in size.
 - True
 - False
- Particles may be trapped on filter material by electrostatic attraction.
 - True
 - False
- Which of the following are physical principles utilized in filtration of particles?
 - Inertial impaction
 - Gravitational settling
 - Laplace law
 - A and B
- Which of the following are characteristics of mechanical filters?
 - Loosely packed glass fibers
 - High resistance to gas flow
 - Tightly packed glass fibers
 - B and C
- Which of the following are characteristics of electrostatic filters?
 - Pleated fiber material
 - More densely packed fiber material than mechanical filters
 - Greater resistance to gas flow than mechanical filters
 - Electrostatic charge
 - All the above
 - None of the above
- Electrostatic filters have less airway resistance than mechanical filters.
 - True
 - False
- A HEPA filter classified as H12 will filter out 85% of all particles.
 - True
 - False
- Which of the following are potential hazards of breathing system filters?
 - Increased airway resistance
 - Increased deadspace
 - Carbon dioxide rebreathing
 - All of the above
- There is an overwhelming body of evidence supporting the use of breathing system filters to reduce VAP and healthcare-associated asthma.
 - True
 - False
- There is limited data supporting the use of bacterial filters to decrease late-onset, hospital acquired VAP.
 - True
 - False

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Objectives

Upon completion of the course, the reader was able to:

- List the mechanisms of action of breathing system filters;

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- Describe the different types of breathing system filters;

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- Describe the methods of testing breathing system filters and their effectiveness;

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- List clinical applications and hazards of using breathing system filters;

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- Describe current studies/data on the effectiveness of the use of breathing system filters.

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- Please indicate your agreement with the following statement. "The content of this course was presented without bias of any product or drug."

Strongly Agree	Strongly Disagree
1 2 3	4 5 6

Answers

- | | | | |
|---|---|----|---|
| 1 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 9 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |
| 2 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 10 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |
| 3 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 11 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |
| 4 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 12 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |
| 5 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 13 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |
| 6 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 14 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |
| 7 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 15 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |
| 8 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D | 16 | <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D |

Name & Credentials _____

Position/Title _____

Address _____

City _____ State ___ Zip _____

Phone # _____

Fax # or email _____

AARC Membership # _____

Credit given only if all information is provided. Please PRINT clearly.