
Respiratory Filters and Ventilator-Associated Pneumonia: Composition, Efficacy Tests and Advantages and Disadvantages

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20.1 Introduction

Respiratory filters (also known as bacterial or microbial filters) are devices with a high capacity to prevent the passage of microorganisms [1] and are placed in the breathing circuit in order to protect the patient from possible respiratory infections carried by the respirator.

The use of respiratory filters was proposed after the reports between 1952 and 1972 of several outbreaks of respiratory infection attributed to contamination of anesthesia machines [2–4].

However, the results of later studies showed no contamination of patients by anesthesia machines, and vice versa [5–9], and that they could have undesirable effects [10] and did not decrease the incidence of ventilator-associated pneumonia (VAP) in clinical studies [11–13]; therefore, its usefulness is questioned.

20.2 Composition of Respiratory Filters

The internal component of the filters can be composed of different materials [1]: wool, foam, paper, polypropylene, polysulfone, ceramics or glass fibers.

20.3 Mechanisms of Filtration Microbiological Respiratory Filters

Filters can have different mechanisms of microbial filtration [1]: (1) mechanical filtration, (2) electrostatic filtration and (3) filtration bactericides.

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1. Mechanical filtration is determined by several aspects. First, the size of the filter's pores causes the organisms to be retained on a relatively large filter surface. Second, the provision of nonlinear irregular pores determines the course of airflow and causes an increase in inertial force that traps the microorganisms within the mesh. The pore size can allow interception of organisms larger than 1 μm and thanks to the nonlinear arrangement of the pores increases their ability to filter microorganisms larger than 0.5 μm . This principle has the limitation that the mesh of tiny pores has high resistance to airflow.
2. The electrostatic filter is produced by the fibers of the internal components of the filter being subjected to an electric field. Bacteria and viruses also have a surface electric charge, either positive or negative, and remain trapped in the dipole electric fields of the filter screen.
3. The bactericidal filter is made by impregnating the filter material with bactericidal agents. Their action allows the growth of bacteria within the filter. For this purpose, antiseptic substances such as chlorhexidine acetate have been used. They are not recommended because they can dissolve in the condensate circuit and reach the tracheobronchial tract.

20.4 Efficacy Tests of Respiratory Filters

Microbial filtration efficiency of the filters is assessed by challenge with a microbial aerosol [1]. An aerosol with a microorganism and a known concentration is generated, then the aerosol is passed through the filter and the concentration examined after passing through the filter. Filter efficiency is analyzed by an aerosol with different organisms; a comparison is made of the concentration of microorganisms in the gas applied to the filter and the effluent gas after it has passed through the filter.

The filtration efficiency is evaluated for bacteria and viruses. Bacterial filtration of tiny *Pseudomonas* or *Serratia marcescens*, which have a diameter of 0.3 μm , was evaluated. Viral filtration efficiency was evaluated with the hepatitis C virus, which has a diameter of 0.03 μm .

Many experimental studies have verified the ability of antimicrobial filters to prevent the passage of microorganisms. Some filters examined in the filtration efficiency tests in vitro reached values of bacterial filtration efficiency greater than 99.999% [1].

20.5 Insertion in the Respiratory Circuit

Respiratory filters are inserted in the breathing circuit with a conical socket of 15 mm diameter (in the area of the patient) and a conical plug of 22 mm diameter (in the area of the respirator). This prevents the disconnection of the breathing circuit, which would endanger the patient's life.

20.6 Functions of the Filters According to Their Location in the Breathing Circuit

The functions of microbial filters vary depending on their location in the breathing circuit: (1) In the inspiratory limb, they can prevent antegrade infection of the patient by the respirator; (2) in the expiratory limb, they can prevent the retrograde infection of the patient by the respirator; (3) interposed between the “Y” part and the endotracheal tube, they can have both functions.

20.7 Disadvantages of the Respiratory Filters

Antimicrobial filters involve some undesirable effects [10]: (1) increased resistance to inspiratory airflow, (2) increased resistance to expiratory airflow and (3) an increase in the dead space of the breathing circuit.

1. The antimicrobial filters cause an increase in expiratory flow resistance, which can promote air trapping within the patient’s lungs. Pulmonary air trapping can have different implications: (a) hemodynamic deterioration, (b) risk of pneumothorax and (c) impaired gas exchange. Pulmonary air trapping leads to increased intrathoracic pressure, which causes the venous return, and therefore can decrease cardiac output and blood pressure. One of the mechanisms of the production of pneumothorax is increased intrathoracic pressure, and this increase appears with air trapping. Moreover, this can also cause air trapping impaired gas exchange because of changes in ventilation/perfusion of the lung, and therefore lead to the development of hypoxemia and/or hypercapnia. This effect could appear when the filter is interposed between the “Y” part and the endotracheal tube or is located in the expiratory limb (immediately before the expiratory valve of the respirator).
2. Respiratory filters produce an increase in inspiratory flow resistance, which may have implications for the patient and the respirator. This increase in inspiratory flow resistance increases the work of breathing of the patient to initiate inspiration and may hinder weaning from mechanical ventilation. Besides, this increase in inspiratory flow resistance also increases the work of breathing for inspiration, and positive pressure can damage the mechanism of the respirator. This effect can appear when the filter is interposed between the “Y” part and the endotracheal tube or is located in the inspiratory limb (immediately after the ventilator inspiratory valve).
3. The bacterial filters generate an increase in dead space because the air space does not participate in gas exchange and can lead to hypoventilation and the development of hypoxemia and/or hypercapnia. This effect can appear when the filter is interposed between the “Y” part and the endotracheal tube.

20.8 Advantages and Disadvantages of the Different Types of Respiratory Circuits Based on the Location of the Filters

The different breathing circuits used, based on the location of respiratory filters in the circuit, have different advantages and disadvantages. In a breathing circuit with one filter, the filter is interposed between the “Y” part and the endotracheal tube. The advantage of a filter circuit with one filter is that the initial economic cost is lower (because there is only one filter). The disadvantages of using one filter are the increased dead space in the circuit and that the filter has to be changed often as it gets contaminated by patient secretions from coughing.

In a breathing circuits with two filters, one is placed in the inspiratory limb (immediately after the ventilator inspiratory valve) and another in the expiratory limb (immediately before the expiratory valve of the respirator).

The advantages of circuits with two filters are that there is no increasing dead space and no risk of having to change filters because of contamination by patient secretions. The disadvantage of using two filters is that the initial breathing circuit is more expensive (because there are two filters).

20.9 Contribution of Anesthesia Machines in Respiratory Infection

The issue of whether contaminated ventilators and anesthesia machines are the origin of nosocomial pneumonia is controversial, with some data implicating them [2–4] and others not [5–9].

Reports from 1952 to 1972 on several outbreaks of respiratory infections attributed the contamination to anesthesia machines [2–4]. However, none of the reports presented a bacteriological demonstration of a cause-and-effect relationship; however, the study by Tinne et al. reported that the same isolate of *Pseudomonas aeruginosa* responsible for an outbreak of postoperative pneumonia was cultured from the corrugated tubing of an anesthesia machine and from Ambu bags [3].

Contrarily, several studies have shown no contamination of the patient by the anesthesia machine and vice versa [5–9]. In some studies [5, 6] of anesthetized patients with and without respiratory infection, samples were taken from several sites of the anesthesia machine and breathing circuits before and after anesthesia, and no differences were found in the contamination of the anesthesia machine and breathing circuits in either patient group. Other studies [6–9] have simulated the contamination of an anesthesia machine by intentional contamination of the expiratory limb of the breathing circuit with an inoculum of an organism, after the sterilization of the anesthesia machine and the entire respiratory circuit, and with continued contamination of the anesthesia machine and breathing circuit inspiratory limb. The authors suggest that the absence of contamination of the anesthesia machine and breathing circuit inspiratory limb is because microorganisms cannot live in the

breathing circuits, because the circulating gas is cold and dry (characteristic of medicinal gases), which hinders the survival of microorganisms.

20.10 Efficacy of the Respiratory Filters to Reduce the Incidence of Ventilator-Associated Pneumonia (VAP)

In an attempt to prevent ventilator-associated pneumonia by contamination of respirators and anesthesia machines, inserting respiratory filters in the breathing circuits has been proposed.

Some authors have suggested that respiratory filters could reduce the incidence of respiratory infections associated with mechanical ventilation because of a reduction in the incidence of infections acquired by exogenous pathogenesis [4], i.e., those infections that are caused by microorganisms that do not colonize the oropharynx at the time of diagnosis. This decrease in exogenous respiratory infection processes could be due to the fact that microbial filters in respiratory circuits could reduce the risk of exogenous microorganisms reaching the patient antegradely from the inspiratory valve of the respirator or retrogradely from the exhalation valve of the respirator.

However, in clinical studies respiratory filters have failed to reduce the incidence of ventilator-associated pneumonia in patients on anesthesia machines [11, 12] and in critically ill patients [13]. In 1981, Garibaldi et al. [11] examined 520 patients on anesthesia breathing circuits with filters (inspiratory and expiratory) or without filters, and found no difference in the cumulative incidence of ventilator-associated pneumonia (16.7% vs. 18.3%). In 1981, Feeley et al. [12] studied 293 anesthetized patients, a group with a filter circuit in the inspiratory limb and one without filters, and no differences in the cumulative incidence of ventilator-associated pneumonia between the two groups (2.2% vs. 2.5%) was found. In one study carried out by our team, 230 critically ill patients were randomized to receive mechanical ventilation with and without respiratory filters. We did not find significant differences between patients with and without respiratory filters in the percentage of patients who developed VAP (24.56% vs. 21.55%), in the incidence of VAP per 1000 days of mechanical ventilation (17.41 vs. 16.26 without BF) or in the incidence of exogenous VAP per 1000 days of mechanical ventilation (2.40 vs. 1.74) [13].

20.11 Recommendations of the International Guidelines for the Use of Antimicrobial Filters in Respiratory Circuits

In the guidelines of the Centers for Disease Control and Prevention (CDC) for the prevention of VAP published in 2004 [14], no recommendation was made for or against the use of respiratory filters in breathing circuits of respirators, either with hot water humidifiers or with heat and moisture exchangers, or in breathing circuits of anesthesia machines, because there is insufficient evidence or consensus on their effectiveness.

The guidelines of the Canadian Critical Care Society published in 2008 did not recommend using respiratory filters [15].

The guidelines of British Society for Antimicrobial Chemotherapy published in 2008 recommended the use of expiratory filters for patients suffering from highly communicable infections (e.g., human coronavirus) and who require mechanical ventilation to reduce the contamination of ventilator circuits (although they do not reduce the VAP risk) [16].

In the guidelines published in 2008 by the Society for Healthcare Epidemiology of America/Infectious Diseases Society of America (SHEA/IDSA) [17] and in those published by two different European working groups in 2009 [18] and 2010 [19], there were no reviews of the issue of preventing VAP.

The CDC guidelines for preventing the transmission of *Mycobacterium tuberculosis* recommend the use of respiratory filters in patients with suspected or confirmed bacillary pulmonary tuberculosis undergoing mechanical ventilation [20].

20.12 Conclusion

Outbreaks of VAP were associated with the contamination of anesthesia machines from 1952 to 1972; however, none of the reports presented a bacteriological demonstration of a cause-and-effect relationship.

Bacterial filters have been interposed in respiratory circuits to avoid VAP caused by contamination of ventilators and anesthesia machines.

The use of respiratory filters has not decreased the incidence of VAP in patients using anesthesia machines and in critically ill patients.

Besides, respiratory filters could have some undesirable effects, such as an increase of resistance to inspiratory airflow, increase of resistance to expiratory airflow and increase of dead space in the breathing circuit.

The use of respiratory filters is not routinely necessary; however, they should be used in patients with suspected or confirmed highly communicable respiratory infections (such as bacillary pulmonary tuberculosis) and who require mechanical ventilation.

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