APPARATUS

BACTERIAL RETENTION PROPERTIES OF HEAT AND MOISTURE EXCHANGE FILTERS

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SUMMARY

We have examined the properties of six heat and moisture exchange filters (HMEF) to ascertain their resistance to liquid flow and their ability to retain a challenge bacterium, Pseudomonas diminuta, from aqueous and nebulized suspensions. Only one HMEF, the Pall Ultipor was able to withstand a significantly greater pressure of liquid than that found in clinical practice. However, when breached, the HMEF were unable to prevent transmission of micro-organisms from aqueous suspension. Only the Durex Hydrobac filter failed to meet the manufacturer’s claim for filter efficiency for nebulized bacteria, mainly because the filter housing failed under test. When the reduction in bacterial cells after passage of the nebulized Pseudomonas diminuta through the HMEFs was analysed statistically, the data showed that the HMEF produced by Pall (Ultipor) and Intersurgical (Filter therm) were superior to those produced by DAR Mediplan (Hygrobac), Intertech (HME 225-2835-800) and Gibeck (Humid-vent). (Br. J. Anaesth. 1992; 69: 522–525)

KEY WORDS


Heat and moisture exchange devices (HME) have been in clinical use for more than 30 years. With no moving parts and requiring no external source of energy, their use as conservers of heat and moisture in breathing systems has considerable attraction. HME provide humidification to the respiratory tract; tests on moisture exchange efficiency have shown humidity values in the range 25–28 mg H\textsubscript{2}O/litre of expired air [1–5]. HME reduce perioperative heat loss [5,6] and postoperative shivering [6]. They are cheaper and more convenient to use than hot water humidifiers and reduce entrainment of water by ventilator tubing and valves; this minimizes damage to equipment and helps to reduce the possibility of ventilator malfunction and its consequent risk to the patient [7].

Early designs of HME had multiple layers of wire gauze mesh or polished metal tubes placed in parallel as the condensation surface, but these had problems of increased resistance to gas flow because of blockages and bacterial colonization. Paper-based condensation surfaces resolved some of these earlier difficulties; their performance was better than their metal counterparts, but the humidity was generally less than that produced by heated humidifiers. A further advance was made with the introduction of devices that used plastic foam impregnated with a hygroscopic substance as the active element. More efficient paper materials have also become available with the result that, currently, the most efficient HME filters use a paper-based surface. The discovery that hydrophobic filter membranes also possess heat and moisture exchange properties [5] has led to further development in this area of work, as they enable moisture retention with the added advantage of efficient bacterial filtration or retention. Efficient microbial filtration may be especially important in the infected or immuno-compromised patient in the intensive care unit and so, subsequently, heat and moisture exchange filters (HMEF), which combine the humidification properties of the HME with the bacterial retention properties of a filter membrane, have been developed. Such devices are designed to protect both patients and ventilators from microbial cross-contamination [8]. Previous comparative studies identified those HME that provided humidification of the respiratory tract, but showed that, at that time, only one was an effective bacterial filter [3,4]. Since then, several HME have been developed possessing both a filter membrane and a heat and moisture exchange membrane. Unfortunately, no comparative evaluation has been undertaken of these newer products. In-house data from companies provide some information about their performance but, in the majority of cases, it is not possible to use these data to compare different brands of HMEF, particularly for bacterial filtration efficiency. The aim of this study was to compare the bacterial filtration properties of HMEF currently available. We have compared the efficiency of the devices when challenged with airborne bacteria and also investigated their liquid filtration properties and resistance to liquid flow.
MATERIALS AND METHODS

We have examined six brands of heat and moisture exchange filters: Darex, Hygrobac; Gibeck, Humidvent; Intersurgical, Filta therm; Intertechn, HME 225-2835-800; Pall, Ultipor; DAR Mediplan, Hygrobac.

Bacterial aerosol challenge test

Preparation of test culture. Pseudomonas diminuta (NCIB 11091) was used throughout the study. The stock organism was maintained on blood agar plates at 35 °C and recultured regularly to maintain the vigour of the micro-organism. The purity of the culture was confirmed periodically using test strips (API 20E) and microscopical examination.

Bacteria grown on blood agar plates were harvested into tryptone soya broth (TSB) immediately before use. The total bacterial cell count was estimated using a haemocytometer counting chamber and the concentration adjusted to approximately 10^8 organisms ml^-1 using TSB. The viable count of the suspension was measured, after 10-fold serial dilution with TSB, by surface spread plate techniques onto blood agar plates.

Apparatus and test procedure. The test procedure was based upon the method of Duberstein and Howard [9] (fig. 1). For each test, an aliquot of a suspension of the Ps. diminuta test culture (5 ml) was nebulized in a DeVilbiss No. 40 nebulizer using a Medicaid CR 60 nebulizer pump operating at 7 litre min^-1. The total flow rate was made up to 25 litre min^-1 with compressed air, supplied through a 0.45-μm filter. The aerosol thus generated was directed onto the patient side of the test HMEF via stainless steel tubing (i.d. 22 mm; length 1 m). Downstream of the test HMEF, two impingers (Porton AGI-30), each containing sterile water 20 ml, were used to collect bacteria. The experiment was run for 15 min, during which time approximately 1–1.5 ml of the suspension had been nebulized. On completion of the test, the water in the impingers was removed using a sterile syringe and each impinger jet and associated glassware rinsed with another 20-ml aliquot of sterile water. All fluids were then pooled.

The viable count of the pooled sample was measured both by serial dilution and by total filtration. A 2-ml aliquot was taken from the final sample and serially diluted as above. The remaining solution was filtered through a 0.22-μm membrane filter and the filter cultured on blood agar plates. All plates were incubated at 35 °C for 2 days.

The apparatus was stripped daily and sterilized by autoclaving. Between tests the components downstream of the test filter were dismantled and disinfected with 70% isopropyl alcohol. All components were rinsed thoroughly with sterile distilled water before reuse.

The efficiency of recovery of organisms from the test rig was established by carrying out several runs (n = 21) without a test filter in place. The aerosol size range generated by the nebulizer was established by the use of an Anderson six-stage sampler in place of the impingers.

Where possible, replicate analyses were performed on a minimum of 10 filters and the results analysed statistically using Tukey’s test [10].

Liquid bacterial challenge test

A length of 22-mm anaesthetic hose was attached to the patient end of the HMEF, the hose suspended vertically above the filter and 100 ml of the challenge suspension of Ps. diminuta introduced into the column. The liquid was allowed to run through the HMEF and was collected in a sterilized glass measure. After 60 min, the total viable counts in both the challenge suspension and the filtrate were measured, after 10-fold serial dilution with TSB, by surface spread plate techniques onto blood agar plates.

Resistance to liquid flow

A length of 22-mm anaesthetic hose was attached to the patient end of the HMEF and the hose suspended vertically above the filter. Water was added slowly to the length of hose until evidence of breakthrough was seen. The height and volume of water above the filter surface at the point of breakthrough was noted.

RESULTS

Aerosol filtration

Using the apparatus without a filter in situ established that, over 21 blank runs, an average recovery of only 8.8% of Ps. diminuta from the overall challenge was achieved. Losses may be attributed to a number of causes. Many organisms collide with the stainless steel tubing and do not reach the impingers. Also, organisms damaged by the shear force of nebulization or the osmotic shock of collection in the impingers do not survive.

Microbiological test methods are known to show significant biological variability, therefore it was considered necessary to do replicate analyses on at
least 10 filters in order to average out these variations. Results from the Anderson samples indicated that 83% of particles generated were less than 3.3 μm in size.

To enable a comparison of filter performance, it was assumed that the true challenge to the filter would be only 8.8% of organisms in the total volume of aerosol that was nebulized.

The filtration efficiency, \( E \), was calculated as follows:

\[
E = 100 - \frac{100 \times n}{C}
\]

where \( n \) = total number of viable organisms recovered downstream of the filter and \( C \) = challenge to the filter, calculated as follows:

\[
C = 0.088 \times N_0 \times V
\]

where \( N_0 \) = initial concentration of organisms in the challenge suspension (CFU ml\(^{-1}\)) and \( V \) = volume of suspension nebulized.

Results from the aerosol filtration studies are shown in table I. Each filter is characterized by filtration efficiency. In addition, as the reduction of micro-organisms is over several orders of magnitude, data are presented as log reductions of the challenge after passage of the aerosol through the filters. Filtration efficiencies were generally very good; consequently, the log reductions were analysed statistically and used to compare the performance of the filters. A log reduction of 8 was assumed, when no micro-organisms were recovered during the test, as this corresponded to the minimum detectable log reduction under the experimental conditions.

On the basis of filtration efficiency, the performance of the Darex HMEF was significantly poorer than the five other brands \((P < 0.05)\). It should be noted that only five samples of the Darex filter were available for testing. These subsequently proved to be old stock of indeterminate age and history. One of these filters failed under the test conditions. In this instance, the adhesive bond between the filter and the housing parted because of the increased pressure developed during the test, thus allowing bacteria to bypass the filter. Because of the small sample size and the unknown history of the samples, these results were not considered further. The results show, however, that the test method was capable of identifying faulty and poor quality filters. The filtration efficiencies \((E)\) of the other filters were statistically indistinguishable.

With the exception of Darex filters, the design of which has since been altered, all HMEF met their performance specifications for bacterial filtration efficiency, as detailed in the manufacturers’ literature.

The log reduction in bacterial numbers proved to be more discriminatory than the filtration efficiency. After statistical analysis using Tukey’s test the following could be concluded:

1. The performance of the Darex filters was significantly worse than that of the five other brands \((P < 0.05)\). This confirms the conclusion from the filtration efficiency data; the reasons for this have been discussed above.

2. There was no significant difference between the DAR, Gibeck and Intertech brands \((P > 0.05)\).

3. There was no significant difference between the Intersurgical and Pall brands \((P > 0.05)\).

4. The difference in the log reductions for the Pall and Intersurgical brands and the four remaining brands was significant \((P < 0.05)\). Therefore the performance of the Pall and Intersurgical filters was superior to that of the DAR, Gibeck and Intertech products.

**Resistance to liquid flow**

Data on the load of water pressure that HMEF were able to withstand are shown in table II. Because of the variable dead volume of the devices, the results are quoted as both volume of water and height of pressure head. The hydrophobic membrane of the Pall filter had by far the greatest resistance to the flow of water. The results for the other devices were similar to each other.

HMEF vary in materials and construction, with consequent differences in hydrophobic properties, deadspace and surface area. However, because of their small pore size and hydrophobic construction, membrane filters are generally more resistant to liquid penetration than the fibrous felt types. The hydrophobic membrane withstood a pressure greater than that likely to be encountered in the worst clinical situation (> 70 cm). All the other HMEF retained liquid challenges within the range 10–15 cm H\(_2\)O, which is equivalent to or slightly greater than the pressure conditions normally found in anaesthetic breathing circuits.

**Liquid bacterial filtration**

The aerosol challenge test is designed to test the efficiency of the HME filter medium when challenged with dry, individual viable particles. In the clinical situation, it is more normal to find humid conditions and, in many cases, liquid mucus. Therefore liquid filtration properties are sometimes seen as important performance criteria for HME filters.

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**TABLE I. Results of aerosol filtration tests for Ps diminuta.** *One of the filters failed under test—data excluded*

<table>
<thead>
<tr>
<th>Brand</th>
<th>Mean log ( \times 10^2 ) reduction</th>
<th>Mean filtration efficiency, ( E )</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darex, Hygrobac</td>
<td>1.733</td>
<td>95.57</td>
<td>5*</td>
</tr>
<tr>
<td>DAR, Hygrobac</td>
<td>5.003</td>
<td>99.9986</td>
<td>10</td>
</tr>
<tr>
<td>Gibeck</td>
<td>4.267</td>
<td>99.96</td>
<td>10</td>
</tr>
<tr>
<td>Intersurgical</td>
<td>7.704</td>
<td>99.9999</td>
<td>10</td>
</tr>
<tr>
<td>Intertech</td>
<td>4.666</td>
<td>99.991</td>
<td>10</td>
</tr>
<tr>
<td>Pall Ultipor</td>
<td>7.002</td>
<td>99.998</td>
<td>10</td>
</tr>
</tbody>
</table>

**TABLE II. Resistance to liquid flow: hydrostatic head required to breach filters (mean of two measurements)**

<table>
<thead>
<tr>
<th>Brand</th>
<th>Volume (ml)</th>
<th>Height (cm H(_2)O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAR, Hygrobac</td>
<td>107</td>
<td>13</td>
</tr>
<tr>
<td>Gibeck, Humidvent</td>
<td>68</td>
<td>10</td>
</tr>
<tr>
<td>Intersurgical, Filtration</td>
<td>78</td>
<td>14</td>
</tr>
<tr>
<td>Intertech, HMEF</td>
<td>66</td>
<td>14</td>
</tr>
<tr>
<td>002835</td>
<td>450</td>
<td>104</td>
</tr>
<tr>
<td>Pall, Ultipor</td>
<td></td>
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</tr>
</tbody>
</table>
During this test, the volume of challenge suspension used provided approximately 23 cm of hydrostatic pressure, with slight variations because of the deadspace of individual filter designs. This pressure was sufficient to breach all filters except for the Pall membrane. There was little reduction in the bacterial concentration of the filtrates compared with the challenge suspensions. When the filter element was breached, none of the HMEF was effective as a filter for a liquid suspension of bacteria. However, the head of pressure required to break through the Pall membrane was far in excess of that found in clinical practice. Until this pressure was reached, no liquid and therefore no bacteria may penetrate this filter.

**DISCUSSION**

The aerosol challenge test used in this paper was designed to test the efficiency of the HME filter medium when exposed to nebulized viable organisms. Under the conditions used, with the exception of one device, all the filters complied with their manufacturer's specifications. No filter is guaranteed to be an absolute barrier and organisms may penetrate it if the challenge is large enough. There is currently no absolute filtration standard for these devices, but clearly the greater the filtration efficiency, the smaller the risk of contamination of the anaesthetic system.

In the clinical situation it is normal for the breathing systems to operate under humid conditions, and in many cases liquid secretions may be present. The liquid challenge and the resistance to flow tests demonstrate that contaminated fluids can soak into and through HMEF at working pressures. Clinically, it has been demonstrated that blood also passes through a filter [11]. Our results show that the hydrophobic filter used in this study continued to act as a barrier to fluids at pressures considerably in excess of those normally encountered in anaesthesia. The question therefore arises as to whether it is clinically preferable to prevent passage of liquid secretions and risk occlusion or to allow the passage of such fluids and risk contamination. There are reports of obstructions attributable to liquid build up [12, 13]; however, the build up of secretions can be monitored through the transparent sides of the devices and potential problems of occlusion or contamination can therefore be averted.

**ACKNOWLEDGEMENTS**

The authors wish to thank Mr Phil Rowe, School of Pharmacy, the Liverpool John Moores University, for assistance with the statistical analyses, and Mersey Health Care, Supplies for funding for one of the authors (P.W.S).

**REFERENCES**