Air flow resistance of three heat and moisture exchanging filter designs under wet conditions: implications for patient safety

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Heat and moisture exchanging filters (HMEFs) can be blocked by secretions. We have studied HMEF performance under wet conditions to see which particular design features predispose to this complication. Dar Hygrobac-S (composite felt filter and cellulose exchanger), Dar Hygroster (composite pleated ceramic membrane and cellulose exchanger) and Pall BB22-15 (pleated ceramic membrane) HMEFs were tested. Saline retention, saline concealment, and changes in air flow resistance when wet were assessed. The cellulose exchanger in the composite Hygrobac-S and Hygroster retained saline, producing a 'tampon' effect, associated with bi-directional air flow resistances in excess of the international standard of a 5 cm H2O pressure drop at 60 litre min⁻¹ air flow. Furthermore, high air flow resistances occurred before free saline was apparent within the transparent filter housing. The pleat only BB22-15 showed a significant increase in expiratory air flow resistance, but only after the presence of saline was apparent. These data imply that composite HMEFs with cellulose exchangers are more likely to block or cause excessive work of breathing as a result of occult accumulation of patient secretions than pleat only HMEFs.

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Heat and moisture exchanging filters (HMEFs) are often used in intensive care to maintain airway humidification and prevent breathing apparatus contamination. Most work concerning the safety of HMEFs in this setting has concentrated on the risk of tracheal tube blockage, a complication that is recognized as inversely related to the moisture output of the device concerned.¹ Accumulation of excess condensation or patient secretions within HMEFs may increase work of breathing² and cause device blockage.³ Most manufacturers warn users of this possibility.

We have examined the performance of three HMEFs under wet conditions in an attempt to determine whether any particular design features might predispose to such complications. The test procedure described assumes that the coexistence of the following factors could cause blockage: (1) a device would have to retain secretions, (2) the retained secretions should not be apparent on inspection of the device, and (3) they would increase air flow resistance across the device.

Methods and results

Dar Hygrobac-S, Dar Hygroster, and Pall BB22–15 HMEFs were studied. All have a transparent plastic housing. The Dar Hygrobac-S is of composite design utilizing both an electrically charged felt filter and a separate cellulose heat and moisture retaining element. The Dar Hygroster is of composite design with a pleated ceramic filter and a cellulose based heat and moisture exchanging element. The Pall BB22-15 is a pleat only design using a pleated ceramic membrane, which acts both as a filter and a heat and moisture exchanger.

Retention testing

Increments of 5 ml 0.9% saline were instilled into the patient end of the device, which was gently shaken with the

patient end occluded and then inverted to determine if spillage of saline occurred. Further increments were added in this manner and the maximum volume instilled that did not result in spillage was defined as the ‘retention volume’.

**Concealment testing**

Increments of 5 ml 0.9% saline were instilled into the patient end of the device, which was gently shaken with the patient end occluded and then inspected for the appearance of free saline within the patient side of the device housing. Further increments were added and the maximum volume instilled that did not result in the appearance of free saline was defined as the ‘concealment volume’.

**Dead space testing**

The dead space of the device on the patient side was measured by adding 1 ml saline increments to the patient end of vertically mounted devices up to the point of spillage. Five devices of each type were used for each of the above test sequences and mean (SD) values calculated. Retention and concealment volumes were expressed as a percentage of the device dead space on the patient side (Table 1).

**Resistance to air flow with incremental fluid challenge**

The resistance of each device was measured by connecting it to a continuous air flow generated by a non-invasive pressure support ventilator (BiPAP S/T-D30, Respironics) and the pressure drop across the device measured using a certified calibration analyser (RT-200, Allied Healthcare Products). An air flow of 60 litre min\(^{-1}\) was used for all pressure drop measurements.

Inspiratory flow resistance was measured by connecting the air flow to the non-patient end of the vertically mounted device (patient end uppermost). After baseline testing the device was removed from the test rig and 5 ml of 0.9% saline instilled into the patient end. The device was gently shaken with the patient end occluded, reinserted into the test rig and the measurement repeated. Testing continued with the addition of further aliquots of saline until the air flow through the device resulted in ejection of saline from the patient end. Expiratory flow resistance was similarly measured but with the air flow connected to the patient end of the device and with testing continuing until the resistance presented by the filter exceeded the pressure generating capabilities of the BiPAP S/T-D30 (30 cm H\(_2\)O).

Ten devices of each type were tested for each air flow direction and mean (SD) values calculated (Table 2).

**Comment**

This study is limited by the use of saline as a test liquid. Some previous work in this area has been undertaken using water.\(^1\) It would be interesting to look at a range of test liquids, but the variable composition of patient secretions opens the choice of any test liquid to criticism. Blockage is a recognized complication of HMEF usage and most manufacturers warn users of the potential for accumulated secretions to cause occlusion. The cellulose exchanger of the composite HMEFs in this study retained and concealed large volumes of saline (Table 1). This

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**Table 1** Volumes (SD) of saline retained and concealed by devices, also expressed as a percentage of the device patient sided dead space

<table>
<thead>
<tr>
<th>Dead space (ml)</th>
<th>Retention volume (ml)</th>
<th>Concealment volume (ml)</th>
<th>Retention volume (% dead space)</th>
<th>Concealment volume (% dead space)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dar Hygrobac-S</td>
<td>33.6 (0.5)</td>
<td>25 (0)</td>
<td>20 (0)</td>
<td>74 (0)</td>
</tr>
<tr>
<td>Dar Hgyroster</td>
<td>56.6 (1.5)</td>
<td>25 (0)</td>
<td>25 (0)</td>
<td>44 (0)</td>
</tr>
<tr>
<td>Pall BB22-15</td>
<td>53.8 (2.4)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

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**Table 2** Effect of incremental saline challenge on mean (SD) pressure drop across devices at 60 litre min\(^{-1}\) inspiratory and expiratory air flow. *Inspiratory testing was continued with the addition of further saline until air flow resulted in the ejection of saline from the patient end of the device. **Expiratory testing was continued with the addition of further saline until the resistance presented by the filter exceeded the pressure generating capabilities of the flow generator (30 cm H\(_2\)O)

<table>
<thead>
<tr>
<th>Saline challenge (ml)</th>
<th>Inspiratory pressure drop (cm H(_2)O) across devices</th>
<th>Expiratory pressure drop (cm H(_2)O) across devices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DAR Hygrobac-S</td>
<td>DAR Hgyroster</td>
</tr>
<tr>
<td>0</td>
<td>3.3 (0.32)</td>
<td>3.4 (0.23)</td>
</tr>
<tr>
<td>5</td>
<td>3.8 (0.43)</td>
<td>3.5 (0.33)</td>
</tr>
<tr>
<td>10</td>
<td>4.3 (0.61)</td>
<td>3.9 (0.35)</td>
</tr>
<tr>
<td>15</td>
<td>5.7 (1.11)</td>
<td>5.1 (1.27)</td>
</tr>
<tr>
<td>20</td>
<td>10.8 (3.40)</td>
<td>7.2 (1.46)</td>
</tr>
<tr>
<td>25</td>
<td>13.6 (2.40)</td>
<td>8.8 (0.43)</td>
</tr>
<tr>
<td>30</td>
<td>Ejection*</td>
<td>Ejection*</td>
</tr>
<tr>
<td>35</td>
<td>&gt;30**</td>
<td>&gt;30**</td>
</tr>
</tbody>
</table>
produced a ‘tampon’ effect associated with bi-directional air flow resistances well in excess of the international standard of a 5 cm H₂O pressure drop across the device at 60 l min⁻¹ air flow (Table 2). The ‘tampon’ effect was most pronounced in the DAR Hygrobac-S, which had the greatest retention volume when expressed as a percentage of the patient sided device dead space (74%). In the clinical setting such secretion accumulation might be detectable if blood stained or purulent but contamination with clear secretions would not be obvious.

The pleat only HMEF showed a significant increase in expiratory air flow resistance (Table 2) but only after the saline was seen (Table 1). If hanging down and collecting secretions, a pleat only HMEF could allow inspiration, but prevent expiration. However, the filter would have to be held in a dependent position for sputum retention to occur and the patient’s attendants would have to fail to notice that the filter housing was full of secretions. Our data suggest that secretions would be seen before expiratory air flow resistance increased significantly.

The superior moisture output of composite HMEFs results in a lower incidence of tracheal tube blockage in comparison to pleat only devices. However our data imply that composite designs may have greater potential to block or cause excessive work of breathing from occult accumulation of patient secretions. In the UK, the Medical Devices Agency performs regular evaluations of HMEFs, however, these are performed in accordance with the International Standard for Anaesthetic and Respiratory Equipment test procedure and do not include a liquid challenge. Testing under wet conditions would provide clinicians with useful information when assessing the safety profile of individual devices and in particular would allow comparison between different designs of composite HMEFs with regard to the risk of device blockage.

References
3 Prasad KK, Chen L. Complications related to the use of a heat and moisture exchanger. Anesthesiology 1990; 72: 958

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