Heat and moisture exchangers in mechanically ventilated intensive care unit patients: A plea for an independent assessment of their performance

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**Objective:** To determine whether use of a hygroscopic and hydrophobic heat and moisture exchanger (HME) for 7 days without change affects its efficiency in long-term, mechanically ventilated, chronic obstructive pulmonary disease (COPD) patients.

**Design:** Prospective, randomized, controlled clinical study comparing two combined HMEs.

**Setting:** Medical intensive care unit at a university teaching hospital.

**Patients:** Long-term, mechanically ventilated, COPD patients compared with non-COPD patients.

**Interventions:** In the first part of the study, COPD patients were studied with the Hygroster HME changed once a week. For the second part, the Hygroster was assessed in non-COPD patients and compared with the Hygrobac HME used in COPD and non-COPD patients for 1 wk without change. Devices could be changed if hygrometric measurements indicated insufficient humidity delivery.

**Measurements and Main Results:** Daily measurements were recorded for inspired gas temperature and relative and absolute humidity. Ventilatory variables, clinical indicators of efficient humidification, were also recorded. No tracheal tube occlusion occurred. However, contrary to the manufacturer advertisement, the Hygrobac experienced surprisingly low values for absolute humidity in both COPD and non-COPD patients. Such events did not occur with the Hygrobac. Absolute humidity measured in COPD patients was identical to that measured in the rest of the study population with both HMEs.

**Conclusions:** Manufacturer specifications and bedside measurements of absolute humidity differed considerably for the Hygroster, which in certain instances did not achieve efficient humidification in both COPD and non-COPD patients. This did not occur with the Hygrobac, which performed well throughout the 7-day period in both COPD and non-COPD patients. Our results speak for independent and in vivo evaluation of HMEs. (Crit Care Med 2003; 31:699–704)

**Key Words:** heat and moisture exchanger; acute respiratory failure; mechanical ventilation; absolute humidity; humidification of inspired gases; chronic obstructive pulmonary disease

During mechanical ventilation of critically ill patients, heat and moisture must be added to the inspired gases to counterbalance their loss resulting from the bypass of the upper respiratory tract by the endotracheal tube (ETT) (1–3). This process has been achieved efficaciously for many years by heated humidifiers (4). More recently, disposable devices called heat and moisture exchangers (HMEs) have been available to clinicians. During the last decade, these devices have been increasingly used in intensive care units (ICUs), as an alternative to heated humidifiers, more so in Europe (particularly in France) than in North America (5). This is in part due to the fact that their clinical (6–10) and hygrometric (11–15) performance compare favorably with those of heated humidifiers. In addition, they decrease the workload of the nursing staff (6, 7, 10) and have been shown to reduce the cost of mechanical ventilation (6–8, 10, 16–18). Unlike heated humidifiers, they are not associated with water condensation in the circuit, which may be a source of cross contamination or infection (19), and thus reduce circuit contamination (7). Manufacturers recommend a daily change of the HMEs. However, this recommendation is not substantiated by independent clinical data. Thus, it may be questioned if the duration of use of a given HME can be prolonged. Several clinical studies have provided solid evidence suggesting that some HMEs could be used for longer periods of time than that indicated by the manufacturer (10, 18, 20–24). Extending the duration of use of these devices had no adverse effect for the patients but enabled substantial reduction in the cost of mechanical ventilation. However, a major, unacceptable drawback could arise from this attitude (25). Indeed, one could legitimately fear a progressive decrease over time in the humidity delivered by the HME to the patient, leading to the potential threat of ETT occlusion. It has been shown in a previous study that although absolute humidity (AH) provided by an HME kept for one entire week was constant in the vast majority of the study population, some HMEs experienced a rapid decline in their humidifying performances (22). This rare event was only encountered in COPD patients. As a pre-
caution, it was recommended that this HME (Hygrobac) be used for ≤48 hrs in COPD patients. Thus, the question that remained unanswered is: would an HME providing even greater humidity outputs than the Hygrobac-Dar be stable for 7 days in COPD patients? This question is worth consideration because COPD patients account for >15% of the patients requiring mechanical ventilation in North America and also undergo ventilation for a longer period of time (26). To try to answer it, we evaluated the humidifying performances over a 7-day period of an HME in mechanically ventilated COPD patients. This HME delivered (according to the manufacturer) greater values for AH. Above all, safety issues were closely examined with daily assessment of the humidifying performances of the HME with both clinical evaluation and hygrometric measurements to detect any insufficient humidity. Unexpectedly, the HME humidity performances measured in our institution were significantly lower than that stated by the manufacturer. Consequently, these results were confirmed in non-COPD patients in the second part of the study and compared with the HME we had previously studied (22).

**MATERIALS AND METHODS**

**Study Design**

**Part One.** The first part of the study involved the evaluation of the efficacy of the HME in mechanically ventilated COPD patients. All the COPD patients hospitalized over a 6-month period in the medical ICU of Louis Mourier hospital (a 12-bed ICU in a teaching hospital) who were considered likely to require mechanical ventilation for ≥48 hrs were included. COPD patients were defined according to the ATS statement for the diagnosis of COPD patients (27). These patients were all acutely ill inpatients. Exclusion criteria were profound hypothermia (body temperature, <33°C), a bronchopleural fistula, poisoning with breath-eliminated drugs such as hydrocarbons, and moribund patients. The HME used was the hygrosopic and hydrophobic Hygroster, (Mallinckrodt Medical, Mirandola, Italy), which, according to the manufacturer, provides greater moisture output than the Hygrobac (33.4 mg H2O/L at 500 mL of tidal volume vs. 30.7 mg H2O/L, respectively) and higher temperature output (33.9°C vs. 31.2°C, respectively, with a 500-mL tidal volume). The ventilators used were Siemens Servo 900 D (Siemens-Elema, Solna, Sweden), Bird 8400 Sp (Bird Products, Palm Springs, CA), and Evita 4 (Dräger, Lübeck, Germany) respirators. Each HME was initially set for a period of 7 days, after which it was replaced. Patients ventilated for >7 days could provide several 7-day study periods.

**Part Two.** The second part of the study involved evaluation of the humidifying performances of the Hygroster in non-COPD patients and comparison of its performances with those of the Hygrobac in both COPD and non-COPD patients. After the unexpected results in part one (see below), the humidifying performances of the Hygroster were evaluated in non-COPD patients who were likely to require mechanical ventilation for ≥48 hrs and compared with those obtained with another HME, the Hygroster (Mallinckrodt Medical) in both COPD and non-COPD patients. Patients allocated to the Hygroster HME were provided with HMEs coming from three separate sets of the Hygroster to eliminate technical distortion. To investigate whether poor humidity measurements obtained with an HME were due to the patient’s respiratory conditions or to the HME itself, a patient could be switched on to the other HME tested if AH measured with the first one was <25 mg H2O/L.

**Positioning of the HMEs**

HMEs were placed between the ETT and the Y-piece of the circuit. Particular attention was given to place the HME vertically above the tracheal tube to reduce the risk of partial obstruction of the HME due to refluxed secretions from the tracheal tube (22, 23). Nurses and doctors repeatedly checked the position of the HME.

**Clinical Evaluation of HME Safety and Efficacy**

The variables recorded daily to assess HMEs have already been used in our previous studies (7, 20, 22, 23). These include the number of tracheal suctionings (which are usually performed every 4 hrs and whenever breathing sounds are heard) and peak airway pressures that were recorded every 4 hrs and averaged over 24 hrs (they are subsequently referred to as mean peak airway pressure). Tracheal instillation is not performed systematically in our unit, but it is performed in the rare cases of very thick tracheal secretions.

**Indications for Premature Replacement of HMEs**

There were three indications for premature replacement of HMEs. First, HME obstruction was identified by an otherwise unexplained rise in peak airway pressure and confirmed by visual inspection of the removed filter and the immediate normalization of airway pressure after replacement of HME. Second, endotracheal tube occlusion was prospectively defined as an unexplained and sudden rise in the peak airway pressure without evidence of filter obstruction and an inability to insert a suction catheter through the previously patent tube. Third, an AH of <25 mg H2O/L.

**Hygrometric Measurements**

AH, relative humidity (RH), and tracheal temperature were measured within the first hours and then daily from day 1 to day 7. AH is the amount of water vapor contained in air (mg H2O/L). Absolute humidity at saturation (AHS) is the maximum amount of water vapor that air can contain at a given temperature. RH is the ratio of AH to AHS expressed as a percentage. These variables were measured by psychrometry, a technique widely used in clinical studies that evaluate HME performances (11–15, 22, 23). A device containing two one-way valves inserted between the ETT and the HME allowed separation of inspired and expired gas flows. In the inspiratory part of this device were inserted two thermal probes: a dry one and a wet one. At the same time, a third thermal probe was inserted in the ETT. These three temperatures were recorded after a 30-min period, allowing optimal thermal equilibrium, and then displayed on a chart recorder (Yokogawa, Tokyo, Japan). Room temperature was constant at 23.5–25°C.

The psychrometric method compares the temperatures obtained with each probe placed in the inspiratory part of the separating device. The dry probe is placed upstream and measures the actual gas temperature. The downstream probe is coated with sterile cotton wetted with sterile water. Evaporation around the wet probe in the inspiratory part is proportional to the dryness of the gas. The temperature gradient between the two probes increases as the inspired gas humidity decreases. For instance, when the inspired gas is fully saturated with water (100% RH), there is no thermal gradient.

RH was calculated by reference to a nomogram, taking into account the difference between temperatures measured by the two probes. AHS (100% RH) was calculated with the following formula: AHS (AH) = 16,41563 – 0.731 T + 0.03987 T² mg H2O/L, where T (°C) is the dry probe temperature. AH was obtained with the formula: AH = (AHS × RH)/100 (in mg H2O/L).

**Data Collection**

The following variables were recorded prospectively for all the patients: age, sex, indication for and length of ventilatory support, severity of illness according to the Simplified Acute Physiology Score (SAPS II) (28), ventilatory variables (including tidal volume and Fio2), and body temperature at the time of psychrometry measurement. This protocol was approved by the Institutional Review Board for human studies of the
Clinical indicators of adequate humidification, ventilatory variables, and body temperature

<table>
<thead>
<tr>
<th>Day 0</th>
<th>Hygrometer</th>
<th>Hygrobac</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COPD, n = 14</td>
<td>Non-COPD, n = 6</td>
</tr>
<tr>
<td>Tracheal aspirations, per day</td>
<td>9.3 ± 1.87</td>
<td>10.2 ± 3.55</td>
</tr>
<tr>
<td>ETT occlusion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vt, mL</td>
<td>524 ± 70</td>
<td>522 ± 44</td>
</tr>
<tr>
<td>Body temperature, °C</td>
<td>37.5 ± 0.85</td>
<td>37.2 ± 1.04</td>
</tr>
<tr>
<td>Day 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Paw, cm H₂O</td>
<td>25.5 ± 6.24</td>
<td>26.0 ± 9.80</td>
</tr>
<tr>
<td>Tracheal aspiration, per day</td>
<td>9.6 ± 3.04</td>
<td>11.0 ± 5.22</td>
</tr>
<tr>
<td>ETT occlusion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vt, mL</td>
<td>531 ± 76</td>
<td>536 ± 37</td>
</tr>
<tr>
<td>Body temperature, °C</td>
<td>37.6 ± 0.77</td>
<td>37.2 ± 1.06</td>
</tr>
</tbody>
</table>

COPD, chronic obstructive pulmonary disease; Paw, airway pressure; ETT, endotracheal tube; Vt, tidal volume.

*Or on last day of evaluation in case of cessation of mechanical ventilation before day 7.
Hygroster in COPD and Non-COPD Patients. Ten (six COPD and four non-COPD) patients (Table 1) were evaluated with the Hygroster HME over a 7-day period, providing 12 sets of measurements, six of which completed the 7-day study period, and six did not because of mechanical ventilation withdrawal. No premature HME replacement because of an AH of <25 mg H2O/L occurred with the Hygroster HME. COPD patients did not differ from non-COPD patients with respect to values for AH (Fig. 3).

Comparison Between Hygroster and Hygrobac. humidifying performances of the Hygroster were compared with those of the Hygrobac, both measured in COPD and non-COPD patients. During the 7-day period, the Hygrobac constantly delivered significantly higher values for AH than the Hygroster (Fig. 4). As stated above, no premature replacement occurred with the Hygrobac because of an inadequate AH (22.7 ± 0.54 mg H2O/L), whereas nine premature replacements occurred with the Hygroster (five in COPD patients [part 1] and four in non-COPD patients [part 2]). Three of these nine prematurely removed Hygrosters were replaced by Hygrobac HMEs, and values of AH measured within the same time frame were significantly greater with the Hygrobac than with the Hygroster (29.3 ± 1.5 vs. 22.7 ± 0.54 mg H2O/L, p < .01).

Finally, three distinct batches of the Hygroster were tested during this study. Values of AH did not differ between the three batches: batch A (13 measurements), 27.3 ± 2.2 mg H2O/L; batch B (ten measurements), 28.7 ± 1.8 mg H2O/L; batch C (seven measurements), 25.9 ± 2.2; p = .12.

DISCUSSION

The main findings of this study are the following. The Hygroster was found to deliver very low unexpected values for AH during long-term mechanical ventilation of both COPD and non-COPD patients. Second, long-term mechanical ventilation with this HME changed only once a week. Overall assessment of this strategy proved to be efficient. However, in three instances, hygrometry measurements indicated that AH delivered by the HME was below the threshold prospectively defined by proto-
All three premature HME replacements occurred in COPD patients even though all the other measurements performed in the rest of the COPD population of the study were satisfactory. As a whole, AH measured in COPD patients was slightly but significantly lower than that measured in the rest of the population (22). It thus remained unanswered if these results were due to the HME or to the COPD respiratory condition. This is why we decided to use, in the present study, an HME stated as delivering higher values of AH.

As stated above, we noted that values for AH measured in our patients were significantly lower than values provided by the manufacturer for this HME. Importantly, such observations were noted in both COPD and non-COPD patients. Thus, it seemed that these events were the consequences of the HME performances rather than that of the respiratory conditions of our patients. Apart from the intrinsic capacity of an HME to deliver a certain level of AH, external conditions (ambient temperature and body temperature) may influence HME performance. In the present study, there was no difference between the body temperature of patients in which an HME delivered <25 mg H_2O/L of AH and that of the rest of the study population. There was no difference either in the ambient temperature because our unit has a strictly monitored and regulated temperature of 23–25°C. Two other observations further imply that discrepancies were more likely due to the HME than to environmental or patient-related conditions. First, these low values of AH were measured with the Hygroster in both COPD and non-COPD patients. Second, three patients ventilated with a Hygroster in which a very low AH was measured were subsequently ventilated with a Hygrobac that was found to deliver satisfactory values of AH. One may then argue that we accidentally received a faulty batch of Hygroster HMEs. However, to free us from this hypothesis, we randomly chose Hygroster HMEs from three distinct batches of HMEs that all delivered similar AH. Other investigators have studied the same HME, but for only very short periods of time (14, 30), and have measured in some instances low values of AH with the Hygroster. These observations call for two remarks. First, they build up compelling evidence for the need of independent and in vivo evaluation of HMEs. Indeed, most of the manufacturer indications on HME performance are based on in vitro testing (using the International Standards Organization 9360 water loss method and psychrometry), which may be quite different from the clinical setting, and thus yield values that overestimate actual in vitro performance (31, 32). Psychrometry is the method most often used by clinicians investigating HME performance, and consistent results have been obtained with this method (33). It may also be that some HMEs (because of their shape, the surface area of the humidifying media, the exact nature the media) are more sensitive to the conditions of use than others, thus explaining why, with these HMEs, differences are noted between bench measurements and bedside measurements. Second, these discrepancies cast doubt in the mind of clinicians who need to choose an HME for their patients. Indeed, the major risk associated with HME use is ETT occlusion. It has been shown that ETT occlusion occurs after a gradual reduction of the internal diameter of the ETT (34). In this study, the reduction was significantly greater with poor-performing HMEs than with a heated humidifier or the Hygrobac-Dar HME. This is in agreement with the clinical observations of ETT occlusion reported in the literature that occurred with HMEs exhibiting low values for AH (35–38). Furthermore, the reduction of the internal diameter of the ETT with the Hygrobac HME was not different compared with that observed with a Fisher-Paykel heated humidifier (34). It is therefore clear that HMEs’ performances in terms of heat and humidity outputs may vary considerably from one brand to another (11, 15, 23, 31). Thus, not all available HMEs are appropriate for long-term mechanical ventilation, let alone an extension of their duration of use, and rigorous and independent assessment of such devices must therefore be performed before using them in the ICU.

A possible limitation of our study may reside in the relatively small number of patients. However, the object of the study was to call attention on the risk of under humidification with a given HME. Had we noted only one patient with poor values of AH, it would have been our duty to report it. Although ETT occlusion is currently rare, it may be unfortunately lethal when it occurs. Our data deserve particular attention from clinicians using the Hygroster HME precisely because we observed such an important number of very low values of humidity in a relatively small number of patients. Concerning the Hygrobac HME, our results confirm our previous results that showed that mechanical ventilation could be safely conducted with this HME changed only once a week (22). This HME has been extensively studied and results consistently indicate very satisfactory hygrometric performances (11, 15, 36, 37), even during prolonged use (22, 23).

As medical care improves and becomes more and more technical (and thus more costly), a higher degree of faultlessness of medical equipment (even the most basic) is required by clinicians and expected by patients and their families. Nevertheless, healthcare resources are not infinite, and administrative supervision is more and more watchful of medical expenditure. This is particularly so in ICUs with mechanical ventilation (39). In this respect, HMEs’ performances have greatly improved during the last decade, but they participate in a certain extent to the cost of mechanical ventilation. Thus, extending the use of HMEs is a laudable goal as long as it does not put the patient at risk of ETT obstruction. Our results indicate that this cannot be achieved with the Hygroster but can with the Hygrobac. Clinicians must therefore be aware of important disparity in the performance of HMEs underlined by our study. Our results speak for independent and in vivo testing of HME performance that may help clinicians choose the appropriate HME for their patients, without placing them at risk of ETT occlusion.
REFERENCES