Comparison of the Effects of Heat and Moisture Exchangers and Heated Humidifiers on Ventilation and Gas Exchange During Weaning Trials From Mechanical Ventilation*

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Heat and moisture exchangers (HME) are increasingly used to warm and humidify inspired gases in intubated ventilated patients. But these devices add dead space that may alter the alveolar ventilation. This could impair the efficiency of spontaneous ventilation (SV) during weaning trials from mechanical ventilation. Fifteen patients were tested with an HME (Hygrobac-DAR) and a heated humidifier (HH) (Fischer-Paykel MR 450) in a random order during weaning trials in SV with inspiratory pressure support. Minute ventilation Ve (tidal volume), and respiratory rate were recorded and arterial blood was sampled for blood gas analysis with each device. The HME gave a significantly greater Ve than the HH (9.3±0.8 L/min vs 8.1±0.8 L/min; p<0.005), because of increased respiratory rate (21±2/min vs 19±2/min; p<0.05). Tidal volume was unchanged for HME and HH (470±32 mL vs 458±39 mL). The higher PaCO2 with HME than with HH (44±2 mm Hg vs 42±2 mm Hg; p<0.005) revealed an insufficient alveolar ventilation response to the increase in dead space. Arterial Po2 rose with the HME, but not significantly above the HH values (103±6 mm Hg vs 97±6 mm Hg; p=0.055), possibly because of a positive end-expiratory pressure effect of the HME. The need to increase Ve in SV when an HME is used should be taken into account during difficult weaning from mechanical ventilation.

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Key words: heat and moisture exchanger; heated humidifier; mechanical ventilation; weaning

Abbreviations: HH=heated humidifier; HME=heat and moisture exchanger; IPS=inspiratory pressure support; MV=mechanical ventilation; PEEP=positive end-expiratory pressure; RR=respiratory rate; SV=spontaneous ventilation; Ve=minute ventilation; Vt=tidal volume

The upper respiratory tract filters, warms, and humidifies inspired gases. Since endotracheal intubation bypasses the upper respiratory tract, there is a continuous loss of moisture and heat during mechanical ventilation (MV) that can induce severe airway damage.1-3 Two humidifying devices are commonly used to prevent this deleterious effect: heated humidifiers (HHs) and heat and moisture exchangers (HMEs). Most studies have compared the abilities of the two devices to adequately humidify and warm inspired gases and prevent bacterial and viral colonization.4-8 In contrast, the effects of these devices on the efficiency of ventilation are less well documented. Since HMEs are placed between the endotracheal tube and the Y-piece, they can affect ventilation in two ways. First, they may increase resistance to flow. The consequences of this are limited.9,10 Second, they add a substantial amount of dead space, in contrast to an HH placed in the inspiratory circuit. This reduces alveolar ventilation for a given minute volume. To preserve efficient alveolar ventilation, minute ventilation (Ve) must be increased during controlled ventilation.11
But the effects of HMEs on the process of weaning remain largely unknown, especially in spontaneously breathing patients. The use of an HME could affect this process unfavorably.

We have therefore compared the effects of an HME and an HH on the ventilatory parameters and gas exchange of patients receiving spontaneous ventilation (SV) with inspiratory pressure support (IPS) during weaning trials from MV.

MATERIAL AND METHODS

The patients included in the study had to be able to tolerate the weaning trial. This required ventilatory and hemodynamic stable conditions, no agitation in the absence of sedation, and no clinically obvious respiratory drive disorder. In our unit, weaning from MV using IPS is achieved by gradually reducing the pressure support by 5 cm H₂O steps until the patient requires less than 5 to 10 cm H₂O for at least 6 h. Extubation is considered if the patient’s clinical and blood gas status are correct with these settings (under a fraction of inspired oxygen ≤40%). Two ventilators used were either a Servo 900D ventilator (Siemens; Solna, Sweden) or a César ventilator (CFPO; Meudon-la-Forêt, France). The inspiratory trigger for opening the demand valve was set at -1 cm H₂O.

The patients were studied at a time when rapid extubation was deemed to be feasible, ie, when they had reached an IPS level between 10 and 15 cm H₂O (ie, <15 but ≥10 cm H₂O). The protocol consisted of comparing two consecutive 20-min periods of SV with IPS, one with an HME (Hygrobac, DAR; Mirandola, Italy) positioned between the Y-piece and the tracheal tube and the other with a conventional HH (Fischer-Paykel; MR 450, United States). The Hygrobac HME is a hygroscopic-hydrophobic device with a dead space of 75 mL. The sequence of periods was randomized. Each 20-min study period was preceded by a 20-min adaptation period (to allow the patient to get used to the device and to allow time for the effects of the preceding device to dissipate). The V̇e, tidal volume (Vt), and respiratory rate (RR) displayed on the ventilator were recorded every 2 min throughout the test period and averaged. Radial arterial blood was sampled to determine PaO₂, PaCO₂, and pH at the end of the 20-min period. The reproducibility of the effects of devices was checked by a third 20-min test period whenever possible. This third period (preceded by a 20-min adaptation period) tested the same device as the one that had been studied first, based on the randomized order. Thus, patients could undergo sequences HH-HME-HH or HME-HH-HME. The protocol conformed to the ethical standards of the investigation review board of our institution and all patients gave their informed consent.

The data were analyzed using Student’s paired t test to detect differences between HME and HH. The results for patients who underwent a third test were analyzed by analysis of variance for repeated measures. Correlations were obtained using the least squares method. A p<0.05 was considered as significant. All results are means±SEM.

RESULTS

The 15 patients tested (8 men and 7 women) had a mean age of 63±4 years (range, 36 to 83 years). Their Simplified Acute Physiologic Score¹² at the time of hospital admission was 16±1 (range, 10 to 22). They were intubated and ventilated for acute exacerbation of a COPD (n=5), pneumonia (n=3), congestive heart failure (n=3), altered consciousness (n=3), or status epilepticus (n=1). The mean time receiving MV before the tests was 8±2 days (range, 1 to 31 days). All of the patients, except 2, were extubated 3±1 days after the study. Of these 13 patients who were successfully weaned, 8 were extubated during the 24 h following the study, 4 during the 3 to 7 days following the study, and 1 at day 13. The patients who could not be weaned developed unexpected septic shock, which led to their deaths in the days following the study. At the time of study, the patients were ventilated with an IPS of 12±1 cm H₂O and a fraction of inspired oxygen of 38±2%. Four patients were ventilated with a positive end-expiratory pressure (PEEP) of 3 to 5 cm H₂O.

For the sake of clarity, all paired measurements
Vt measured during breathing with HH and percent change in $V_E$ and $P_aCO_2$ measured during breathing with HME as compared with HH (Fig 3).

A third set of measurements was made on 13 of the 15 patients, but arterial blood gas values were not measured for 2 patients for technical reasons. The results of these measurements show the reproducibility of the effects of a given device. Patients ($n=7$) who had the HME-HH-HME sequence had significantly lower $V_E$ with the HH, which returned to baseline when the HME was retested (8.6±1.1 vs 7.2±0.9 vs 8.8±1.1 L/min; $p<0.001$). In contrast, there was no change in $P_aCO_2$ in this subset of patients (43±4 vs 42±3 vs 44±4 mm Hg; $p=0.2$). Patients ($n=6$) who had the HH-HME-HH sequence had significantly increased $P_aCO_2$ with the HME (39±3 vs 42±3 vs 38±3 mm Hg; $p<0.005$). In contrast, the $V_E$ was unchanged (8.9±1.7 vs 9.8±1.6 vs 9.4±1.8 L/min; $p=0.07$).

**DISCUSSION**

Spontaneously breathing patients with IPS increased their $V_E$ when an HH was replaced with an HME. Despite this, $P_aCO_2$ increased significantly. These changes in ventilation could affect the weaning process unfavorably.

The use of HMEs has become widespread in the ICU in recent years, because of their simplicity of use and their economic advantages. The structure of new-generation HMEs consists of multilayer water-repellent membranes with electrostatic and mechanical filtering power and one hygroscopic membrane that provides the heat and moisture exchanging function. These membranes are housed in a plastic cast. Although the thermal and hygroscopic performances plus the antimicrobial and antiviral filter efficiency of these devices have been investigated quite thoroughly, fewer data are available on their possible interference with ventilatory efficiency. Most of the studies have focused on the increase in the resistive load with HME. In *vitro*, the HME resistance varied as the flow rate and duration of use, and most of the new-generation HMEs have a dry resistance of 1.5 to 3 cm $H_2O$L/s at an airflow of 60 L/min. The HME resistance does not change during controlled ventilation or only moderately increases after 24 h of clinical use. To our knowledge, they did not induce dynamic hyperinflation in the only study carried out on patients with COPD. This small additional resistance probably has a negligible effect on the respiratory work load associated with spontaneous breathings during weaning trials. Few studies have explored the effect of the greater dead space introduced by HMEs. This added dead space may not be negligible. For example, the volume of the HME (Hygrobac DAR) that we used is 75 mL. Alveolar ventilation is thus im-

**FIGURE 3.** The negative correlation between Vt measured during breathing with HH and percent change in $V_E$ (top) and $P_aCO_2$ (bottom) measured during breathing with HME as compared with HH.
paired during controlled ventilation, requiring an increased \( \dot{V}_e \) to maintain a constant \( \text{PaCO}_2 \).\(^{4,11,21} \)

To our knowledge, the effects of HMEs on gas exchange and ventilatory parameters have not been assessed during weaning trials, especially in spontaneously breathing patients. In our study, the term of weaning was used as defined in a recent consensus conference on MV,\(^{22} \) which is a process whereby MV is gradually withdrawn and the patient resumes spontaneous breathing. Since it is difficult to define the precise time at which the discontinuation process commences,\(^{22} \) we used the term of weaning trial to indicate that our study was performed during the gradual process of weaning but was not necessarily immediately followed by extubation. The duration of the weaning process in our patients was similar to that reported in a recent study that compared methods of weaning from MV, including IPS, as in ours.\(^{23} \)

Our study shows that the use of such a device in SV patients with IPS results in a significantly greater \( \dot{V}_e \) than with an HH. This increased \( \dot{V}_e \) results from a higher RR with no change in \( V_t \), probably due to the fact that our patients had a constant IPS, making changes in \( V_t \) less easy than those of RR.\(^{24} \) Nevertheless, the magnitude of the \( \dot{V}_e \) increase was insufficient to effectively increase alveolar ventilation and prevent \( \text{CO}_2 \) retention. As might be expected, the adverse effect of adding dead space with the HME was more pronounced in patients with lower \( V_t \) during HH breathing. This was documented by a negative correlation between \( V_t \) during HH breathing and the changes in both \( \dot{V}_e \) and \( \text{PaCO}_2 \) observed during HME breathing. This indicates that although in many patients the amount of added dead space with an HME is trivial and unlikely to adversely affect weaning trial outcome, this may not be the case in patients with very limited ventilatory reserve such as patients with severe chronic respiratory failure. This also strongly suggests that both increases in \( \dot{V}_e \) and \( \text{PaCO}_2 \) were the result of increased dead space only, although we did not measure the ratio of dead space to \( V_t \). Finally, it is very unlikely that our results are the consequence of any noticeable increased \( \text{CO}_2 \) production. Indeed the stability of our patients was documented by the results of a third study period during which the device used in the first period was retested. We observed that \( \dot{V}_e \) and \( \text{PaCO}_2 \) returned to values similar to those of the first period.

Our results agree with those of a study published in abstract form,\(^{25} \) which showed that when IPS level was regulated to the level of P0.1, the addition of an HME resulted in an increase of both IPS and \( V_t \). An unexpected finding was an increase in \( \text{PaO}_2 \) with the HME which was very close to significance (p=0.055). We have no clear explanation for this, except that the HME may have produced a PEEP effect. Nevertheless, this explanation does not seem to be compatible with the findings of Conti and colleagues.\(^{9} \) They showed that dynamic hyperinflation did not occur in patients with COPD ventilated with an HME. However, there are several differences between the two studies: different HMEs were used, their patients were receiving controlled ventilation, and the RR was much higher in our study (21/min) than in theirs (10 to 12/min). Thus, increased expiratory resistance cannot be excluded in our patients. Documentation of this putative increased resistance was beyond the scope of our study. Although we studied one HH and one HME model only, our findings are likely generalizable to other models. Indeed, by definition, HHS do not add dead space whereas all types of HMEs add some. Perhaps, HME models with a less important dead space than in this study would have less marked adverse effects.

The use of an HME might alter the outcome of weaning trials, especially in very weak patients. Indeed, although we did not measure respiratory muscle work, the increase in \( \dot{V}_e \) resulting from the added dead space may lead to an overload of respiratory work.\(^{26} \) To our knowledge, no study has compared the outcome of weaning trials for patients with HMEs or with HHS. The clinical significance of the modest changes in \( \dot{V}_e \) and \( \text{PaCO}_2 \) that we observed remains to be determined. Pending the results of further studies, physicians should therefore be aware that HMEs may be unsuitable for difficult-to-wean patients.

**References**
