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Humidification During Noninvasive Ventilation in the Critically Ill

To the Editor:

Although humidifiers have demonstrated beneficial therapeutic effects during nonin-

vasive ventilation (NIV), there is still controversy over the selection of the best humidifier to improve patient-ventilator interaction and gas exchange.¹ We read with interest the recently published study by Lellouche et al,² who analyzed the short-term effects of 2 types of humidifiers: heat and moisture exchanger (HME) and heated humidifier. The authors hypothesize that humidifiers may influence gas exchange and mechanical ventilation parameters. However, there are some important issues related to the methodology and interpretation of data that need to be discussed.

First, the study population was diverse (including both hypoxemic and hypercapnic respiratory failure). The different pathophysiological mechanisms of the 2 problems may influence the effects of humidifiers.¹

Second, the results related to some measured ventilatory parameters need further discussion: tidal volume and minute volume ($\dot{V}_E$); HME internal dead space; HME internal resistance and performance; NIV air flow; and evaluation of P_{CO_2} control and efficacy.

Tidal Volume and Minute Volume

In this study there was no difference in the expired tidal volume between the HME and the heated humidifier: median (IQR) 535 mL (456–638 mL) versus 545 mL (453–667 mL).² It is not clear in the methodology where the expired tidal volume was measured. Moreover, the paper did not discuss the potential effects of humidification devices on the in-line measurement of tidal volume, which theoretically may influence the volume delivered to the patient. On the other hand, $\dot{V}_E$ was different with the HME and heated humidifier: median (IQR) 15 L/min (12–18 L/min) versus 12 L/min (10–16 L/min), respectively ($P < .001$). High $\dot{V}_E$, particularly in patients with hypercapnia and acidosis, could have a significant effect on the internal resistance of HMEs.^{3–5}

HME Internal Dead Space

The average dead space in the Lellouche et al study was of 22–95 mL (mean 60 mL).² In an earlier study the same group measured the internal resistance of different HMEs and reported varied internal resistances.⁶ The results obtained in this study cannot be generalized to all HMEs, as there are several HMEs with different dead space. The

authors selected in their recent study the lower resistance model, with a dead space above the mean reported in their previous study.⁷ The potential clinical implications of this were not discussed in the paper.² Currently there are no studies that have evaluated the effect of a variable dead space and internal resistance of HMEs on patients during NIV.

HME Internal Resistance and Performance

Although the internal resistance of the HME is usually very low, it remains an important factor to consider when selecting humidifiers, particularly when higher air flow and $\dot{V}_E$ are used.^{3,4} In some cases, sub-optimal pressure support levels may be insufficient to overcome the humidifier's internal resistance and, hence, may lead indirectly to a slower decrease in P_{aCO_2} , as shown in the current study.² Such effect will be of greater relevance in patients with higher degrees of expiratory air flow obstruction and acidosis.⁸ As the pulmonary function test values of the study population were not reported in this study, it is difficult to comment on this issue.

Air Flow During NIV

The performance of the HME was described in a previous bench study at air flow of 60 L/min, which is much lower than the air flow used during NIV.⁷ Therefore, it is important to evaluate the effect of air flow on the performance of HMEs in patients during NIV.

Evaluation of P_{CO_2} Control and Efficacy

The authors attributed the slower control of P_{aCO_2} levels to the increased HME dead space; however, this finding can be interpreted differently. In this study, breathing frequency was significantly higher in the HME model, compared to the heated humidifier model: 27 breaths/min (23–33 breaths/min) vs 24 breaths/min (20–30 breaths/min), $P < .001$. Breathing pattern and breathing frequency may influence gas exchange results, especially among hypercapnic patients. Elevated baseline P_{aCO_2} may indicate a greater degree and severity of intrinsic PEEP. This aspect cannot be assessed in the current paper because we

have no information about the lung function of the study population. Although the problem of rebreathing is lower with double lumen ventilatory circuits, it may still have a role and affect PaCO_2 behavior and could partly explain the slower decline in PaCO_2 , especially in unstable acidotic patients with lower PEEP setting with HME.

Finally, another limitation of the current study is the lack of data related to the level of leakage, patient comfort, and dryness. The fact that data were collected for a short period is another limitation, because the effectiveness of HMEs is lost over time. Moreover, the study did not assess clinical indicators of effective humidification and did not perform hygrometric measurements.

Comparison between 2 humidification systems requires detailed consideration of technical aspects. Further studies are needed to elaborate more on the findings of this interesting and original study.

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The Authors Respond:

We thank Drs Esquinas and BaHammam for their interest in our paper and for their thorough analysis. It looks like there is still controversy concerning which humidification device to use during noninvasive ventilation (NIV). We will respond point by point to these comments, although some of the responses to questions raised are included in the discussion section of the paper.¹

First, we evaluated different populations on purpose, in order to add to the existing data provided by the previous study performed on COPD patients.² In the present study we found that, in comparison with heated humidifier (HH), heat and moisture exchanger (HME) use during NIV was associated with increased minute ventilation and reduced CO_2 clearance. The impact of the humidification system was present irrespective of the type of respiratory failure (hypoxemic, hypercapnic with or without acidosis), but was greatest in patients with hypercapnic acidosis. These findings are in agreement with Jaber et al, who compared these humidification devices in hypoxemic and hypercapnic patients receiving NIV.³

The questions related to the methodological aspects focus on the measurement of the tidal volumes and the predominant impact of resistance or dead space differences between HH and HME to explain the results.

Tidal volumes were directly recorded from the ventilator after 30 min of NIV conducted with each device, in a randomized order, during stable condition, as specified

in the methods.¹ The study was not blinded and we acknowledge that this may have had an impact on tidal volume recordings, but not on arterial blood gases results. It must be underscored that the breathing pattern differences in the present study are in line with those found in a previous study comparing the same humidification devices while the breathing pattern was measured with a pneumotachograph connected to a differential pressure transducer independent from the ventilator.² In their letter, Esquinas and BaHammam are correct in stating that temperature and humidity may affect the volume of the gases. Fujita et al showed that monitored expiratory tidal volume was underestimated with different ventilators from 8% to 14% when using an HME.⁴ Thus, the difference we found in minute ventilation (15.5 ± 6.4 L/min with HME vs 13.7 ± 5.8 L/min with HH, $P < .001$) may have been even larger if one considers a potential overestimation of volumes with HH.

We do not agree with Esquinas and BaHammam's comments on the role of resistance differences to explain the breathing pattern and arterial blood gases differences between HH and HME. The differences showed are more likely related to the dead space effect. First, there is no clear physiological rationale to explain a lower CO_2 elimination with HME owing to resistance. Second, the HME's resistance is slightly lower than the HH's resistance, due to the wire in the HH circuit (Table 1). In a previous study we showed that the resistance of the HH (MR850 with heated wire in the RT200 circuit lumen) was slightly higher than that of the HME (Hygrobac)² (see Table 1). The characteristics of the humidification devices compared in the present study are described in Table 1. The main difference between the 2 humidifiers used in the present study was the dead space (0 mL vs 95 mL), and we thus conclude that the observed differences are related to the dead space differences. The impact of dead space on breathing pattern and arterial blood gases is well documented during NIV,^{2,3} as well as in intubated patients during assisted ventilation.⁵⁻⁹ We agree that the volume of the HME evaluated in our study is among the highest. However, among the 10 best performing HMEs, half had similar volume.¹⁰ It was shown that during NIV with the use of a low dead space HME and the use of very high tidal volumes, the dead space effect becomes insignificant.¹¹ In many pa-

Table 1. Dead Space and Resistance of the Humidification Devices

	MR850 Heated Humidifier With RT200 Circuit	Hygrobac HME	48 Other HMEs Mean $\pm$ SD (range)
Dead space, mL	0	95*	58 $\pm$ 24 (24–101)
Resistance, cm H ₂ O/L/s†	3.5	2	2.0 $\pm$ 0.6 (0.45–3.5)

* Heat and moisture exchanger (HME) dead space provided by manufacturer.

† Resistance measured on bench (data from References 2 and 10).

Fig. 1. Theoretical impact of the instrumental dead space of the humidification device on the total dead space and consequently on alveolar ventilation (V_{alv}): $V_{alv} = (\text{tidal volume} - \text{total dead space}) \times \text{breathing frequency}$. Total dead space (in red on the figure) includes physiological dead space and instrumental dead space (95 mL for the heat and moisture exchanger [HME]). This example represents alveolar ventilation when the HME (black dots) or the heated humidifier (open circles) are used at different breathing frequencies to obtain a minute ventilation of 10 L/min. Physiological dead space was computed for a woman measuring 1.65 m.^{12,13} While increasing the breathing frequency, the negative impact of HME on alveolar ventilation (and consequently on CO₂ elimination), in comparison with heated humidifier, is more pronounced.

Table 2. Advantage and Drawbacks of Humidification Devices

	Humidification Performance	Dead Space	Resistance	Cost
Passive HME	– to ++	+ to +++	+	–
Active HME	++	++	+	+
Heated humidifier	– to +++	0	0 if heated wire is within the circuit wall + if heated wire is in the circuit lumen	+
In-line vaporizer	+++?	0	$\pm$	++?
Ideal humidifier	+++	0	0	–

HME = heat and moisture exchanger

tients with relatively low tidal volumes (400–500 mL), however, and in the case of high breathing frequency, the instrumental dead space (mostly due to HME), added to the physiological dead space, may impede alveolar ventilation and efficient CO₂ clearance (Fig. 1).^{12,13} The other potential difference between the tested devices is related to the humidification performance, but there is no clear physiological rationale to explain the impact on breathing pattern and arterial blood gases. We agree that with double line circuits the dead space may have a lower impact than with single line circuits; however, the impact of instrumental dead space is not negligible in regard to the small tidal volumes and the relatively high breathing frequencies for critically ill patients receiving NIV (see Fig. 1).

In this study we did not measure humidity nor did we evaluate comfort or leaks. These issues were addressed in a previous study.¹⁴

After several years of research in this field, we are not certain of the impact of humidification during NIV, and it seems that an ideal humidifier may not currently exist for NIV (Table 2). Humidification is probably required in most situations (with the possible exception of short-term NIV with a turbine ventilator at low FIO₂). The effect of HME dead space on breathing pattern and on CO₂ removal must be kept in mind, especially for an individual patient with difficulties in managing NIV. Whether it has a major influence on the success of NIV is not proven.

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