Active Humidification With Boussignac CPAP: In Vitro Study of a New Method

José M Alonso-Iñigo MD, Amadeo Almela MD, Alejandro Albert MD, José M Carratalá MD, and María J Fas MD

OBJECTIVE: To carry out an in vitro study of Boussignac CPAP valve performance with a new humidification method, using a heated humidifier. METHODS: Two heated humidifiers were evaluated: Fisher & Paykel MR850, and Covidien Kendall Aerodyne 2000. Baseline measurements were taken in all experimental conditions without humidification. The Boussignac valve was adapted to the input of the humidification chamber. The system was connected to a test lung to assess the degree of pressurization. Hygrometric and pressure measurements were performed with the following gas flows: 10, 20, 30 and 40 L/min. RESULTS: The mean values of pressure generated by the Boussignac valve were 1.99 ± 0.02, 6.97 ± 0.05, 16.61 ± 0.08 and 21.24 ± 0.08 cm H_2O, 10, 20, 30 and 40 L/min, respectively, no differences being detected between study groups. Overall absolute humidity was significantly greater with a heated humidifier than without humidification (range 40.01 ± 0.57–25.46 ± 0.49 compared to 0.16 ± 0.13 mgH_2O/L, $P < .001$). Absolute humidity was significantly higher in Kendall Aerodyne 2000 compared to MR850, regardless of the selected temperature and flow ($P < .001$). CONCLUSIONS: This new method of Boussignac CPAP humidification yielded humidity values above 25 mg H_2O/L regardless of the heated humidifier and flow used. Pressurization values remained constant in each experimental situation and were not influenced by adding humidification. These data open up the possibility of using Boussignac CPAP on different types of patients, with different interfaces and for long periods of time. *Key words: active humidification; Boussignac; CPAP; noninvasive ventilation; acute respiratory failure.* [Respir Care 2013; 58(4):647–654. © 2013 Daedalus Enterprises]

Introduction

Both noninvasive ventilation (NIV) and CPAP are currently the treatment of choice in various forms of acute respiratory failure.[1,2] Both therapies involve the use of pressurized cold and dry medical gases, with the possibility of signs of dryness in the respiratory tract. The effects of the absence of humidification of inspired gases can on the one hand cause the rejection of this technique due to discomfort, and, on the other hand, the possibility of atelectasis appearing as a result of respiratory secretion dryness.[3] Despite the theoretical benefit of conditioned gas administration, there is currently no clear recommendation regarding the type of humidifier, or the humidification values to be applied during NIV or CPAP treatment in acute respiratory failure.[4]

Dr Alonso-Iñigo is affiliated with the Department of Anesthesiology, Critical Care, and Pain Medicine, Hospital Universitari i Politècnic la Fe, Valencia, Spain. Dr Almela is affiliated with the Short-Stay Medical Unit, Emergency Department, Hospital Universitario Arnau de Vilanova, Valencia, Spain. Dr Albert is affiliated with the Emergency Department, Hospital General Universitario de Alicante, Spain. Dr Carratalá is affiliated with the Short-Stay Medical Unit, Emergency Department, Hospital General Universitario de Alicante, Spain. Dr Fas is affiliated with the Department of Anesthesiology, Critical Care, and Pain Medicine, Hospital Universitario de la Ribera, Alzira, Valencia, Spain.

Dr Alonso-Iñigo has disclosed a relationship with Vygon. The other authors have disclosed no conflicts of interest.

Correspondence: José M Alonso-Iñigo MD, Department of Anesthesiology, Critical Care, and Pain Medicine, Hospital Universitari i Politècnic la Fe, Bulevar Sur s/n 46026, Valencia, Spain. E-mail: jmalonso@me.com.

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Various studies of chronic patients with NIV or nasal CPAP have shown that the absence of humidification increased the resistance in the nasopharynx 3-fold, and that the volume of air decreased during treatment. In these cases, resistance was reduced by administering conditioned air, thereby increasing the volume of air flow and improving tolerance to ventilation.[5,6] In a recent study, several humidification systems were tested on healthy volunteers.[7] They compared the administration of NIV in 3 situations: without humidification, with a heat and moisture exchanger (HME) and with a heated humidifier (HH), using different types of ventilation systems: a turbine ventilator (with an ambient gas mixture), an intensive care ventilator (with pressurized medical gases), and a high flow CPAP (90–150 L/min). The authors of the study noted that administering gases without humidification while using an intensive care ventilator or a high flow CPAP system provided excessively dry air, compared to the turbine ventilator.

The use of different systems of NIV may influence the temperature and humidity of the gases supplied to the patient. Non-mechanical CPAP systems are based on the use of valves and high gas flows to generate continuous pressure. In most cases, the gas flow is obtained from a pressurized source, so it is delivered to patients with very low humidity and temperature. As regards CPAP systems, it is worth highlighting the Boussignac (Vygon, Ecouen, France). This system is a lightweight (10 g) disposable, cylindrical plastic device with an inner diameter of 1.2 cm. It contains no sensors or mechanical valves and was developed to deliver CPAP for face masks and tracheal or tracheostomy tubes. A jet of air and/or oxygen that accelerates through 4 parallel microchannels creates flow-dependent pressure in this plastic tube. Due to the geometry by which the compressed gas is injected into the hollow tube, a turbulent virtual "valve" is created.[8-11] In order to change the level of CPAP, it is sufficient to vary the amount of gas injected into the microchannels: the more gas injected, the greater the pressure generated.

Gases were conditioned through the Boussignac valve by interposing an HME, by connecting an additional gas source connected to a HH, or by adding a normal saline infusion to the secondary port of the Boussignac valve.[11,12] Our hypothesis was that by placing the Boussignac valve at the input of the HH humidification chamber, CPAP would be generated proximally. Thus, the pressurized gas flow that passes through the humidification chamber and the heated limb circuit is conditioned by maintaining levels of CPAP generated proximally. The aim of this study was to perform an in vitro study of CPAP levels and hygrometric characteristics with different active humidification systems by using a new humidification method.

QUICK LOOK

Current knowledge

CPAP in the hospital is often delivered without heated humidification. The optimal heated humidification method to improve patient CPAP tolerance is unknown.

What this paper contributes to our knowledge

Using 2 different heated humidification systems, and placing the CPAP valve proximal to the humidification chamber yielded absolute humidity of > 25 mg H_2O/L, regardless of the humidification system or gas flow used. Humidification was greater with a heated humidifier utilizing a set gas temperature, compared to a setting for noninvasive ventilation.

Methods

Installing the System

The local ethics committee of the Hospital Universitario Arnau de Vilanova approved the study. For the experiment, 2 HHs were used: MR850 (Fisher & Paykel, Auckland, New Zealand) and Kendall Aerodyne 2000 (Covidien, Mansfield, Massachusetts). The MR850 uses a heated pass-over system to add water vapor to the gas flow, whereas the Kendall Aerodyne 2000 uses a heated wick. The Boussignac valve was adapted to the input of the humidification chamber. Both systems employed a heated single-limb circuit. The Boussignac valve was connected to an O_2 mixer with a high-flow flow meter (40 L/min). Thus, CPAP was generated proximally in the circuit by passing the pressurized gas flow through the humidification chamber and heated tubing. The system was connected to a test lung (Training and Test Lung 5600i, Michigan Instruments, Grand Rapids, Michigan) to assess the degree of pressurization in the different phases of the study. A capacitive hygrometer (HygroPalm, Rotronic, Bassersdorf, Switzerland) with a high performance linear probe (HC2-C05, Rotronic, Bassersdorf, Switzerland) was used to measure temperature and relative humidity.

The system incorporates a layer of plastic polymer between 2 electrodes that can absorb molecules of water, depending on humidity. Changes in capacity are correlated to the relative humidity. This system has a very low dead time and is accurate (humidity range 0–100%, temperature range −40°C to 85°C), recording an error of 0°C and no variations over time. At the end of each measurement the tip of the capacitive hygrometer was dried to avoid any possible measurement error. The probe was placed in the distal part of the tube before connecting it to the test lung.

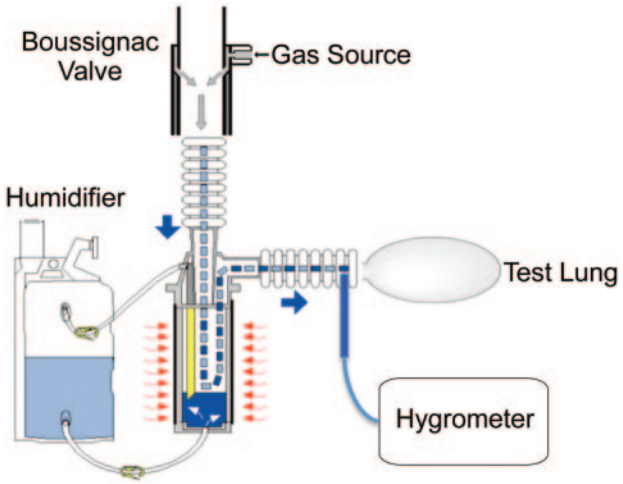

Fig. 1. Experimental setup.

During the experiment we examined relative ambient humidity and temperature and the hygrometric characteristics of the gas mixture flow from the high-flow flow meter using an additional hygrometer (HygroPalm, Rotronic, Bassersdorf, Switzerland) connected to a cylindrical probe (HC2-S, Rotronic, Bassersdorf, Switzerland). (Humidity range 0–100%, temperature range −50°C to 100°C.) Hygrometric data were stored on a computer using specific software (HW4 2.3.0.21699, Rotronic, Bassersdorf, Switzerland) to be later analyzed and calculated. Pressurizing values were collected with the analysis software used for the test lung (PneumoView, Michigan Instruments, Grand Rapids, Michigan) (Fig. 1).

Measurements

The study was conducted under conditions of stable environmental temperature and humidity (20°C and 50% relative humidity), which were measured throughout the experiment, as a means of control. Measurements of relative environmental humidity and temperature were taken every 5 min throughout the various phases of the study. We measured temperature and relative humidity values from the flow meter gas mixture for a period of 15 min (15 measurements) to evaluate the hygrometric characteristics of the pressurized gas source. Hygrometric measurements were performed with the following gas flows: 10, 20, 30, and 40 L/min, obtained by using a high-flow blender (MicroBlender, CareFusion, Yorba Linda, California) with an F_{IO_2} of 0.50. These levels of flow were used to test the performance of the HHs with different CPAP levels. Before modifying the gas flow, the system was stabilized to achieve the target temperature values of the HHs. Under these conditions we tested the performance of both HHs in NIV mode. The MR850 was tested using the active compensation algorithm (software 722) and NIV mode. In the case of the Kendall Aerodyne 2000, which can modify the temperature of the system in NIV mode, measures were taken at 32°, 33°, and 34°C (Fig. 2). In each experimental scenario, baseline measurements were taken without humidification. In each of the phases mentioned above, relative humidity and temperature were measured. We obtained 90 measurements (one measurement per minute for 90 min continuously) in each experimental situation. A total of 1,800 measurements were taken. In order to calculate absolute humidity, the following formulae were used[10]:

$$\text{Saturated absolute humidity} = 16.451563 - 0.731\ T + 0.03987T^2$$

$$\text{Absolute humidity} = (\text{saturated absolute humidity} \times \text{relative humidity})/100$$

where T is the probe temperature in degrees Celsius, and relative humidity, absolute humidity, and saturated absolute humidity are expressed in mg H_2O/L. Pressurization values were measured every 2 min in each experimental phase.

Statistics

Statistical analysis was performed using statistics software (SPSS 16, SPSS, Chicago, Illinois). Descriptive statistics were obtained for all values with the mean and standard deviation. In order to analyze the differences between groups, analysis of variance was used, while the Bonferroni test was employed for multiple comparisons. A P value of $< .05$ was considered statistically significant.

Results

We obtained a total of 360 environmental measurements. Absolute and relative humidity and temperature remained stable throughout the experiment (20.9 ± 0.2°C ambient temperature, 53.8 ± 3.2% ambient relative humidity, 11.2 ± 0.5 mg H_2O/L ambient absolute humidity). The hygrometric characteristics of the gas from the flow meter were 23.3 ± 0.3°C temperature, 3.4 ± 0.5% relative humidity, and absolute humidity 0.6 ± 0.02 mg H_2O/L.

Absolute humidity for the 5 study groups with different gas flows is shown in the Table. Humidification was significantly higher with the Kendall Aerodyne 2000 than with the MR850, regardless of the selected temperature level and gas flow ($P < .001$). For each selected gas flow, absolute humidity was significantly greater if a HH was used than if there was no humidification in the circuit ($P < .001$). The absolute humidity values obtained with the Kendall Aerodyne 2000 increased significantly in relation to the selected temperature, depending on the gas flow employed ($P < .001$).

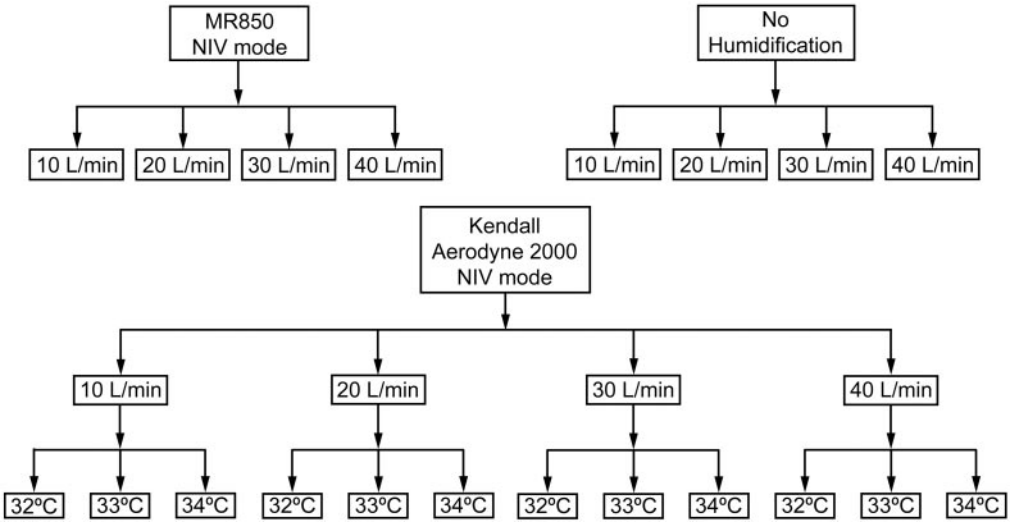

Fig. 2. Study protocol. Ninety measurements were taken in each experimental scenario.

Table. Absolute Humidity With and Without Humidification

		Absolute Humidity, mean ± SD mg H_2O/L				
		10 L/min	20 L/min	30 L/min	40 L/min	Overall
Aerodyne	32°C	36.28 ± 0.92	35.96 ± 0.43	34.49 ± 0.40	34.57 ± 0.53	35.32 ± 0.99
	33°C	38.46 ± 0.45	37.97 ± 0.42	35.92 ± 0.52	36.22 ± 0.68	37.14 ± 1.22
	34°C	38.85 ± 0.57	40.01 ± 0.57	37.82 ± 1.09	38.83 ± 0.35	38.88 ± 1.04
MR850	NIV	26.21 ± 0.96*	25.46 ± 0.49*	26.01 ± 0.24*	26.01 ± 0.48*	26.05 ± 0.61*
No humidifier		0.32 ± 0.06*	0.26 ± 0.01*	0.04 ± 0.01*	0.03 ± 0.01*	0.16 ± 0.13*

* $P < .001$ at all flows for MR850 vs Kendall Aerodyne 2000, and for with vs without humidification.
NIV = noninvasive ventilation

Figure 3 shows the evolution of absolute humidity with gas flow changes in each study group to evaluate the ability of each humidifier to maintain a constant range of values. Humidification values obtained with the MR850 were similar, regardless of the gas flow employed. In the case of Kendall Aerodyne 2000 for a selected temperature of 32°C and 33°C, humidity decreased significantly from 10 to 30 L/min ($P < .001$), remaining similar between 30 and 40 L/min. For a selected temperature of 34°C, humidity values were different in relation to the gas flow employed ($P < .001$), except between 10 and 40 L/min (see Fig. 3). In the group that did not have a humidifier, humidification values decreased significantly as the gas flow increased ($P < .001$).

Figure 4 displays the behavior of temperature. In the case of the MR850, the temperature raised significantly when the gas flow was increased ($P < .001$), except for 30 and 40 L/min, where temperature was similar. The Kendall Aerodyne 2000 at a selected temperature of 34°C witnessed a progressive and significant increase in temperature up to 30 L/min, recording a significant decrease at 40 L/min ($P < .001$). The temperature values with the Kendall Aerodyne 2000 at 33°C were similar between 10 and 20 L/min, producing a significant increase and decrease at 30 and 40 L/min, respectively ($P < .001$). Finally, when the Kendall Aerodyne 2000 was set at a temperature of 32°C, there was also a significant rise in temperature up to 30 L/min ($P < .001$), with a decrease at 40 L/min to similar values to those obtained with 20 L/min (see Fig. 4).

The ability to pressurize the system at each gas flow was stable and remained unchanged, regardless of the type of humidifier employed or whether or not there was a humidifier (Fig. 5). The mean values of pressure generated by the Boussignac valve were 1.99 ± 0.02 cm H_2O, 6.97 ± 0.05 cm H_2O, 16.61 ± 0.08 cm H_2O, and 21.24 ± 0.08 cm H_2O at 10, 20, 30, and 40 L/min, respectively.

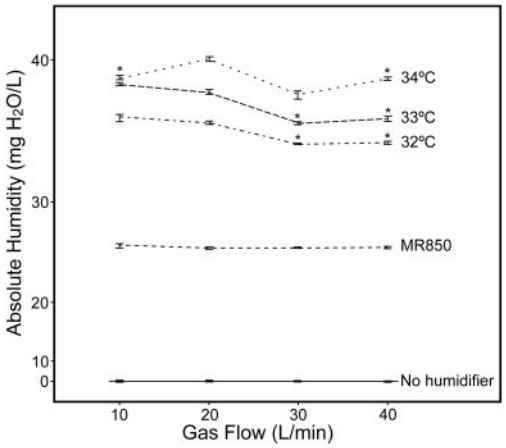

Fig. 3. Evolution of absolute humidity following a change in gas flow in each study group. The data are expressed as mean and 95% CI. $P < .001$ for each study group between different flows, except for MR850, no humidifier, and between those marked with an asterisk in the same study group. The Kendall Aerodyne 2000 was tested at 32°C, 33°C, and 34°C.

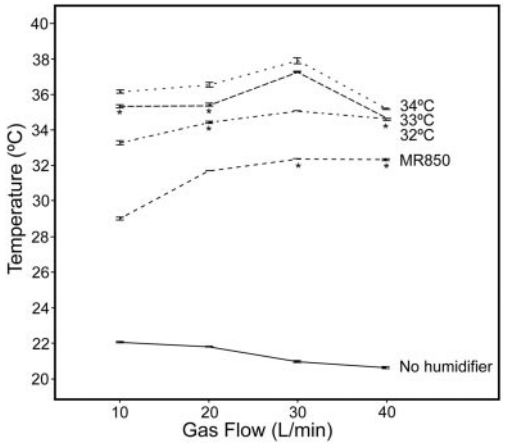

Fig. 4. Evolution of temperature following a change in gas flow in each study group. The data are expressed as mean and 95% CI. $P < .001$ for each study group between different flows, except those marked with an asterisk in the same group of study. The Kendall Aerodyne 2000 was tested at 32°C, 33°C, and 34°C.

Discussion

This study is the first to undertake an in vitro evaluation of Boussignac CPAP and humidifier performance using different active humidification systems by placing a Boussignac valve at the inlet of the humidification chamber. The main results are that this new method yielded similar pressure values at each gas flow employed, regardless of the different experimental conditions, and humidification values were maintained between 25–26 mg H_2O/L and 34–40 mg H_2O/L for the MR850 and Kendall Aerodyne 2000, respectively, compared to those obtained when not using a humidification device (0.04–0.54 mg H_2O/L).

System Evaluation

During NIV the absence of medical gas humidification may cause dryness in the respiratory tract. This effect is greater when CPAP systems based on the administration of high-flow gas are used. In a recent study of healthy volunteers, absolute humidity values were 5 mg H_2O/L when high-flow CPAP was employed through an oronasal mask.[7] In another study similar to the above, but using Boussignac CPAP, the mean value of absolute humidity was 4 mg H_2O/L.[12] The ideal humidification value to preserve the function of the mucociliary system is 44 mg H_2O/L, measured after the carina.[13] Although, upper airways are not bypassed during NIV, high-flow therapy can make physiological gas humidification less effective. These data suggest that the use of humidification systems to condition gas with high-flow CPAP systems may be beneficial to prevent respiratory complications.

There are few studies on how to humidify Boussignac CPAP. Thille et al tested the performance of HME and HH on 9 healthy volunteers and 7 patients with respiratory failure and airway obstruction treated with Boussignac CPAP at a constant level of 7.5 cm H_2O.[12] They used an HH connected to a T-shaped piece inserted between the interface and the Boussignac valve, with an additional source of gas flow between 7 and 12 L/min to add water vapor proximally to the gas supplied to the patient. In both cases, HME and HH to 12 L/min, the values of absolute humidity were approximately 25 mg H_2O/L and therefore significantly higher than the 4 mg H_2O/L measured when no humidification system was used. Although they obtained some acceptable values, the main disadvantages of adding an HH to the circuit is that an additional source of gas is needed for humidification, the additional gas flow must be adapted to the gas flow necessary to generate CPAP, and there is no strict control over the hygrometric and temperature conditions generated within the interleaved T-shaped piece. Furthermore, the performance of an HME would decrease if there were leaks.

In our study, by placing the Boussignac valve directly in the gas inlet of the humidification chamber, the gas flow was humidified and heated immediately after crossing the flow acceleration canaliculi of the valve, being conditioned and pressurized before reaching the breathing simulator. Following this, humidity values were higher than 25 mg H_2O/L regardless of the type of gas flow employed and the type of HH (see Fig. 3). This new method avoids the use of an additional source of gas and maintains hygrometric conditions and temperature stable. Furthermore, the pressurization effectiveness of the Boussignac valve did not change when using an HH, as the pressure values measured in the breathing simulator were similar to those obtained in the absence of humidification.

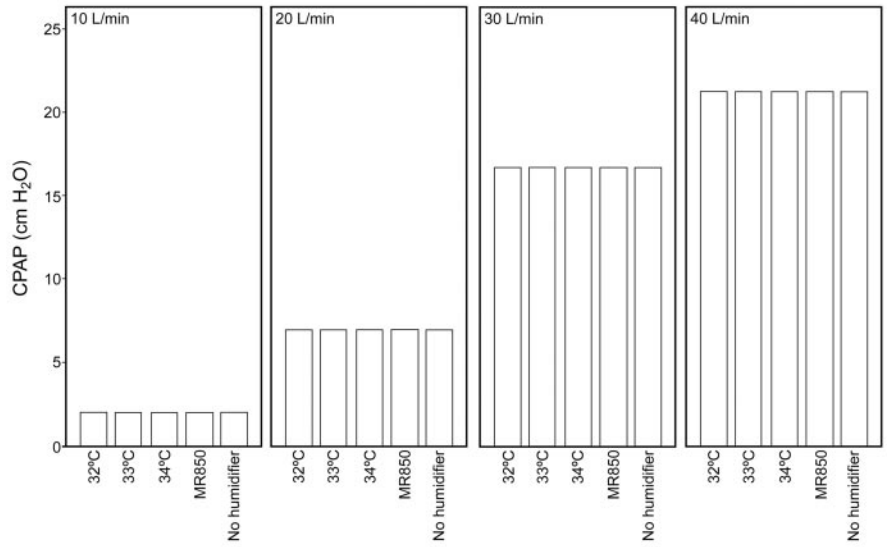

Fig. 5. Pressure levels in each experimental scenario. Data expressed as mean and 95% CI. No differences between groups at the same gas flow.

Heater Humidifier Performance

The 2 types of humidifier employed performed differently. The MR850 was able to maintain constant humidity, recording only minor variations related to changes in the gas flow employed. In the case of Kendall Aerodyne 2000, humidification values varied in relation to the gas flow used, being lower with 30 and 40 L/min, regardless of the temperature selected. Global absolute humidity values were significantly higher with the Kendall Aerodyne 2000, registering more than 33 mg H_2O/L, compared to 25 mg H_2O/L under the MR850 (see Fig. 3). These results are due to the differences in the temperature chamber between the 2 systems.

The MR850 system in noninvasive mode is programmed to generate theoretical values of absolute humidity of 32.1 mg H_2O/L. However, despite the values obtained in our study being lower, the system was still able to provide stable humidification values, regardless of the gas flow employed. This is due to the MR850 flow compensation system, which enables temperature to be matched to the gas flow in the humidification chamber, providing constant humidification values.

The Kendall Aerodyne 2000 provides the possibility of modifying the temperature in the humidification chamber from 32°C to 34°C in noninvasive mode. For these temperatures the theoretical values of absolute humidity would be 33.8, 35.7, and 37.7 mg H_2O/L for 32°C, 33°C, and 34°C, respectively. In our study, despite some minor variations depending on the gas flow used, the values of humidity with the Kendall Aerodyne 2000 were similar to the theoretical temperature selected (see Fig. 3).

The performance of the HH can be influenced by several factors, but the main ones are room temperature and gas temperature before passing through the heating chamber.[14] Studies have shown that an increase in ambient air temperature can negatively affect humidifier performance, especially at values above 26°C, as a result of warm gas flows reaching the humidification chamber from the gas source.[7,14,15] Moreover, the ventilation system used can affect the performance of the HH in relation to the flow generator type used. In a recent study that evaluated the in vitro performance of the Kendall Aerodyne 2000 and the MR850 at different room temperatures and with different ventilators, lower humidification values were observed with respect to those theoretically delivered, regardless of the type of ventilator used.[7] The higher the room temperature (26–28°C) and the higher the output ventilator temperature, the lower these values were. The MR850 with a compensation system performed the best when compared to the Kendall Aerodyne 2000 at the recommended temperature for NIV (31°/34°C).

These data contrast with those in our study because the performance of the Kendall Aerodyne 2000 at 32°C was superior to the MR850, regardless of the gas flow. One explanation for these differences is that our study was carried out in constant gas flow conditions, without inspiratory and expiratory flows, and this could affect HH performance. Another explanation is that the temperature of the gas mixture from the flow meter was about 23°C. These temperature values are high, as wall gases from a pressurized system do not commonly exceed a temperature of 15°C. HHs are unable to control humidity directly, but do so through the temperature. The higher the inlet gas

temperature, the lower the temperature reached in the heating chamber, resulting in a decrease in the formation of water vapor and therefore gas humidity values. Our data suggest that the Kendall Aerodyne 2000 was less influenced by changes in the temperature of the chamber than the MR850.

A bench study that evaluated the humidification performance of 2 HHs (HC100 and MR850 600, Fisher & Paykel) with different inlet gas temperatures showed a decrease in the production of moisture with increasing gas temperature. The values obtained ranged from 36 to 26 mg H_2O/L for a range of inlet gas temperatures of 18°C and 32°C, respectively.[16] The room temperature in our study remained constant at values very close to 21°C throughout the experiment, so their influence on humidifier performance was minimal.

On a different note, the use of a jet system to generate CPAP could influence the temperature of the gas. When the gas enters the microchannels of the Boussignac valve, there could be a loss of temperature as a result of acceleration and the subsequent transmission of part of its kinetic energy to the molecules in the body of the valve. This loss of temperature was greater the higher the flow used, as shown in Figure 4, when no HH was used. These values decreased from 22 ± 0.1°C with 10 L/min to 20 ± 0.20°C with 40 L/min ($P < .001$). Despite the high temperature from the gas source, the optimum room temperatures and the decrease in the temperature of the gas while passing through the Boussignac valve observed in our study could explain why the HH systems performed better (especially the Kendall Aerodyne 2000) in relation to previous studies.[7,14,15] In those studies the use of different types of ventilators produced an increase in ventilator output temperatures that was responsible for lower humidifier performance.

Clinical Implications

Despite the development of different humidification systems during NIV, their use is controversial. Their beneficial effects have been proven in patients with NIV at home. A randomized crossover study carried out on 16 COPD patients with NIV at home recorded a lower incidence of complications and fewer hospitalizations in patients who received active humidification, compared to those treated with HME. Although the differences were not significant, the active humidification group displayed better tolerance to NIV.[16] Other studies have shown that administering conditioned air during NIV or CPAP at home caused less nasal dryness and improved air intake and ventilation tolerance.[5,6]

Patients with acute respiratory failure have different clinical characteristics that may make humidification during NIV beneficial. The use of medical gases, oronasal interfaces, high-flow systems, and clinical conditions such as fever or dehydration contribute significantly to airway dryness and discomfort. This can result in an NIV failure.[4] Despite the theoretical advantages, there are no clear recommendations about the type of humidification system to be used or the type of patient and disease that would benefit from its use.

Which humidity values are optimum during NIV is another point of controversy. In a study of healthy volunteers that compared different humidification systems, comfort scores were similar for humidity ranges from 15–30 mg H_2O/L, whereas no humidification (5 mg H_2O/L) led to comfort scores that were half those provided by HME or HH.[7] These data give an idea of the minimum amount of moisture that would be necessary to supply to patients, although the study assessed only one hour of treatment and was performed on patients without respiratory disease. It seems reasonable to recommend humidity values of $>$ 15 mg H_2O/L, as it has been shown that these values cause only minimal dryness in nasal mucosa.[17,18] Our study, using a new system to humidify the CPAP generated by the Boussignac valve, yielded humidity values higher than 15 mg H_2O/L (ranging from 40.01 ± 0.57 to 25.46 ± 0.49 mg H_2O/L) regardless of the HH and gas flow employed. Absolute humidity values higher than 30 mg H_2O/L have been not tested during NIV, and there are no current published data. Despite this, the theoretical advantages of this new system include the possibility of long-term treatment (hypoxemic patients); avoiding the negative effects of high-flow on the nasopharyngeal conditioning system; constant humidification values, even in the presence of leaks; the use of the Boussignac valve with different active humidification systems; and the possibility of extending the therapeutic scope to patients at risk of secretion retention (the elderly and children) and to different clinical units (ICU, short-stay unit, post-anesthesia care unit).

Another potential indication is the use of humidified Boussignac CPAP for weaning tracheostomy patients. In a recent study, Boussignac CPAP was used successfully on 50 patients with tracheostomy 24 h/d with a median treatment duration of 16 days (interquartile range 11–25 d).[11] CPAP was well tolerated by the patients and contributed to comfort and mobility during weaning. Humidification of the Boussignac CPAP was provided with a standard 50-mL syringe infusion pump connected to the secondary port that delivered normal saline at 4–8 mL/h. Although this is not a real humidification method because it does not add water vapor to the gas flow, there were no tracheostomy tube obstructions throughout the treatment. It is interesting to note in this study that low levels of CPAP (3 cm H_2O at a flow of 8 L/min and 5 cm H_2O at a flow of 15 L/min) were effective in weaning the patients. Finally, note that the humidification system produced no changes in CPAP

levels between the different gas flows employed in our study.

Limitations

Bearing in mind that this is a pilot study that was performed under ideal conditions, the hygrometric values obtained may be different to those obtained in real conditions. In our study, we did not evaluate the effect of the nasopharyngeal conditioning system on temperature and humidity, which in real terms during NIV partially contributes to conditioning inspired gas. It is important to mention that the pressure levels in our study were obtained under ideal conditions without leaks and may therefore differ to those obtained in clinical practice. It would be necessary to conduct clinical studies to ascertain the impact of the level of humidification on patients' comfort and CPAP effectiveness with this new method.

Conclusions

This study describes Boussignac CPAP performance with different active humidification systems. Placing the Boussignac valve proximally in the humidification chamber yielded absolute humidity values above 25 mg H_2O/L, regardless of the HH and gas flow used. Pressurization values remained constant in each experimental situation and were not influenced by the presence or absence of humidification. Hygrometric data obtained without humidification registered a progressive decrease in temperature and humidity in relation to the increase in gas flow, with mean values of absolute humidity near zero. This study suggests a new way of humidifying Boussignac CPAP and opens up the possibilities of using it on different types of patients, with different interfaces, and for long periods of time.

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