

# Mask humidity during CPAP: influence of ambient temperature, heated humidification and heated tubing

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**Purpose:** Mucosal drying during continuous positive airway pressure (CPAP) therapy is problematic for many patients. This study assessed the influence of ambient relative humidity (rH) and air temperature (T) in winter and summer on mask humidity during CPAP, with and without mask leak, and with or without heated humidification  $\pm$  heated tubing.

**Methods:** CPAP (8 and 12 cmH<sub>2</sub>O) without humidification (no humidity [nH]), with heated humidification controlled by ambient temperature and humidity (heated humidity [HH]) and HH plus heated tubing climate line (CL), with and without leakage, were compared in 18 subjects with OSA during summer and winter.

**Results:** The absolute humidity (aH) and the T inside the mask during CPAP were significantly lower in winter versus summer under all applied conditions. Overall, absolute humidity differences between summer and winter were statistically significant in both HH and CL vs. nH ( $p < 0.05$ ) in the presence and absence of mouth leak. There were no significant differences in aH between HH and CL. However, in-mask temperature during CL was higher ( $p < 0.05$ ) and rH lower than during HH. In winter, CPAP with CL was more likely to keep rH constant at 80% than CPAP without humidification or with standard HH.

**Conclusion:** Clinically-relevant reductions in aH were documented during CPAP given under winter conditions. The addition of heated humidification, using a heated tube to avoid condensation is recommended to increase aH, which could be useful in CPAP users complaining of nose and throat symptoms.

**Keywords:** continuous positive airway pressure, humidification, temperature, leakage

## Introduction

Acceptance of continuous positive airway pressure (CPAP) therapy may be compromised by side effects. Up to 70% of subjects using nasal CPAP report symptoms such as nasal congestion, dry nose and throat, sneezing, sore throat, epistaxis and discomfort associated with dry cold air.<sup>1-3</sup> These may reduce the acceptance of therapy and CPAP efficacy.<sup>3,4</sup> It has been shown that subjects on CPAP with mouth leakage for > 70% of their total sleep time (TST) had significantly lower compliance.<sup>5</sup>

Heated humidification (heated humidity [HH]) prevents upper airway dryness and has been shown to significantly improve CPAP-related side effects.<sup>6-8</sup> A number of studies have attempted to determine the relationship between HH use and CPAP compliance. While one showed a significant increase in compliance within 35 min of the addition of HH,<sup>9</sup> two of three trials included in a meta-analysis found the addition of HH had no effect and the other reported a small but significant compliance

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improvement in the HH group.<sup>10</sup> However, even with the addition of HH, a decrease in relative humidity (rH) during CPAP with mouth breathing cannot be fully prevented, and subjects may still experience nasal irritation and dryness.<sup>11</sup> It is difficult to achieve optimal humidification because inspired air temperatures of > 30°C are not well tolerated. However, to minimize dehydration of the mucous membranes humidification is a useful addition to CPAP therapy. Buildup of condensation in the tube and mask is another potential issue during use of CPAP with HH. If saturation in the tube exceeds the dew point (100% saturation), water vapor condenses and forms droplets, causing sleep disruption.<sup>12</sup> Heated tubing has been developed which increases air temperature, improves the ability of inhaled gases to transport water, and prevents condensation. However, use of heated tubing has not yet been shown to improve compliance with CPAP.<sup>6</sup>

The ideal level of humidification during CPAP has not yet been clearly defined. Martins et al<sup>11</sup> found that mouth leakage under CPAP during sleep reduced the rH from 60 ± 14% to 43 ± 12%. During periods of CPAP with mouth breathing, HH was able to increase the rH by up to 60 ± 14%, but this was still 20% below rH achieved during HH without mouth leaks (81 ± 14%). rH values of > 80% during CPAP with mouth leakage can also be attained by using a face mask.<sup>11</sup> However, many subjects find a nasal mask more comfortable than a face mask,<sup>13</sup> but an rH value of ≥ 80% should be the target during CPAP using a nasal mask and with mouth leakage to ensure adequate hydration of the nasal and pharyngeal mucosa. Traditionally, CPAP HH devices had a single adjustable subject control which set the temperature of the water heater to a constant level throughout the night. This does not respond to changes in ambient temperature and humidity, potentially contributing to ineffective humidification. In contrast, new generation CPAP devices monitor set pressure, airflow, and ambient temperature and humidity, and can optimize rH.

The influence of ambient conditions on humidity delivery of new CPAP humidification systems, and the impact of mask and mouth leak on humidity reaching the upper airway are not well understood. Therefore, this study assessed the extent to which humidity in the mask is influenced by rH and ambient air temperature (T) in two different seasons (winter and summer) and by mask leaks during CPAP, with and without heated humidification and with heated humidification using a heated tube.

## Methods

Patients with obstructive sleep apnea (OSA) were eligible for this open-label observational study (NCT01462409).

The study protocol was approved by the ethics committee of the University of Witten-Herdecke. All patients gave written informed consent to participate in the trial, which was conducted in accordance with Good Clinical Practice and the Declaration of Helsinki.

## Study design

Investigations were performed in the morning (09:45 to 11:45 h), in awake, supine subjects. The three different CPAP conditions were applied in a random order: CPAP with no humidification (no humidity [nH]); CPAP with standard heated humidification (HH); CPAP with heated humidification using a heated tube climate line (CL).

## Equipment

The same CPAP device (S9; ResMed Germany, Martinried, Germany) was used for all experiments. This device automatically regulates the temperature and RH of inhaled air using various sensors, including a temperature sensor in the tube near the mask. For HH experiments, the humidifier was set to the recommended level of 3 out of 6, resulting in delivery of 80% rH and a temperature of 27°C. When using the heated tube, the system was set to a temperature of 27°C which provides approximately 80% relative humidity (21 mg/L ambient humidity).

The temperature and humidity sensor was the Mini-humidity/-temperature-Module 0628 0008, probe tip 49 × 18 × 7 mm (Fa Testo, Lenzkirch, Germany), the sampling rate was 0.5 Hz, and aH was calculated using the following equation:

$$aH \text{ (mg/L)} = rH \times (0.0387 \times T_2 - 0.6066 \times T + 13.776).^{14}$$

## Masks

The same nasal mask with an identical leakage opening (Mirage SoftGel, Size M; ResMed Germany) was used. A port near the mask was opened to simulate mask leak. For each humidification circuit, nasal CPAP (nCPAP) was applied at pressures of 8 and 12 cmH<sub>2</sub>O for 5 min each, without leakage (nL) and with leakage (wL). Flow through the mask vent at 8 and 12 cmH<sub>2</sub>O was 28.5 and 36.5 L/min, respectively. The simulated leak increased the flow rate to 48.1 and 60.1 L/min, respectively.

## Assessments

rH and temperature in the nasal mask during CPAP were measured over 5-min periods under each condition (nH, HH, CL), using an integrated temperature and humidity sensor.

Periods were randomized and the patient was blinded to the applied mode. After each condition the participants estimated their subjective comfort on a 5-item scale (0–4).

## Ambient room conditions

Summer and winter measurements were performed during the respective seasons (with the window open in winter). Before and after each experiment, the temperature (T, °C) and rH of room air were recorded using the same sensor as in the mask.

## Statistical analysis

Results are presented as mean  $\pm$  SD. The nonparametric Wilcoxon signed rank test and the Mann–Whitney U test were used to compare paired and unpaired parameters. Statistical analyses were carried out using WinSTAT® software (Cambridge, MA, USA). A two-sided *p*-value of  $< 0.05$  was considered statistically significant.

## Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standard of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

## Results

### Participants

Eighteen patients with OSA were included. Seven patients were assessed during winter group and 11 during summer. Patient demographic and clinical data are shown in Table 1.

### Room temperature and humidity

In summer, mean ambient room temperature was  $20.7 \pm 0.46^\circ\text{C}$  and rH  $58.8 \pm 5.2\%$ ; corresponding values for winter were  $14.3 \pm 0.84^\circ\text{C}$  and rH  $44.6 \pm 8.8\%$ .

**Table 1** Subject characteristics

Characteristics	Overall (n=18)	Summer (n=11)	Winter (n=7)
Age, years	54.3 $\pm$ 8.5	54.5 $\pm$ 7.9	54.0 $\pm$ 7.8
Height, cm	179.9 $\pm$ 8.4	179.4 $\pm$ 5.2	180.9 $\pm$ 5.1
Weight, kg	102.7 $\pm$ 20.6	98.9 $\pm$ 17.0	108.6 $\pm$ 15.1
BMI, kg/m <sup>2</sup>	31.6 $\pm$ 5.4	30.7 $\pm$ 4.6	33.1 $\pm$ 4.5
ESS score	9.8 $\pm$ 5.9	8.9 $\pm$ 5.8	11.3 $\pm$ 5.0
AHI baseline, /h	31.9 $\pm$ 22.0	26.6 $\pm$ 21.3	41.5 $\pm$ 21.0
CPAP, cmH <sub>2</sub> O	9.0 $\pm$ 2.4	8.6 $\pm$ 2.2	9.6 $\pm$ 2.8

**Notes:** Values are mean  $\pm$  standard deviation.

**Abbreviations:** BMI, body mass index; ESS, Epworth Sleepiness Scale; AHI, apnea-hypopnea index; CPAP, continuous positive airway pressure.

### CPAP without humidification (nH)

Compared with summer, aH inside the mask was significantly lower during winter. Increasing flows as a result of increasing pressure and leakage were associated with further decreases in aH in both summer and winter (Table 2).

### CPAP with controlled heated humidification (HH)

There was a significant increase in aH with HH versus nH during both summer and winter. The relative difference in aH with HH vs. nH was significantly greater in winter (Table 2). Based on the values obtained, the HH system appeared able to adequately compensate for additional mask leak added to the circuit, stabilizing temperature and humidity.

### CPAP with controlled humidification and tube heating climate line (CL)

aH values during the use of CL were similar to those during use of HH (Table 2). Temperature in the mask was significantly higher ( $p < 0.05$ ) and aH was significantly lower in summer vs. winter; rH was lower during winter but comparisons with summer values were not statistically significant.

### Between-group differences in humidity

In summer, rH was significantly higher in both the HH and CL conditions compared with nH, and with HH vs. CL (all  $p < 0.05$ ). However, during winter, rH in the CL group was  $< 80\%$  and only significantly increased compared with nH at a CPAP pressure of 8 cmH<sub>2</sub>O ( $p < 0.05$ ). In winter, only HH was associated with an rH above 80% ( $p < 0.05$  vs. nH and CL) but values were numerically lower than those during summer. Levels of aH were similar with both HH and CL, and were both significantly increased compared with nH at both CPAP pressures (all  $p < 0.05$ ). However, as for rH, values for aH were numerically lower in winter in all applied humidification groups.

### Relationship between temperature and humidity

The relationship of both rH and aH to T is represented graphically in Figure 1. In winter, rH was always above the dew point in the HH group, sometimes in the CL group and never in the nH group. Under summer conditions, rH was above the dew point more often, apart from in the nH group. Absolute humidity was almost never above the dew point in winter in any group, whereas in most patients in the HH and CL group the aH was above the dew point in winter.

**Table 2** Relative humidity (rH), temperature (T) and absolute humidity (aH) during continuous positive airway pressure (CPAP) therapy under different humidification conditions, with and without additional mask leakage, at two pressure levels (8 and 12 cmH<sub>2</sub>O), in summer and winter

Setting	Summer				Winter			
	8 cmH <sub>2</sub> O		12 cmH <sub>2</sub> O		8 cmH <sub>2</sub> O		12 cmH <sub>2</sub> O	
	No mask leak	With mask leak	No mask leak	With mask leak	No mask leak	With mask leak	No mask leak	With mask leak
<b>No humidification</b>								
rH, %	74.2±6.6	72.0±6.9	70.1±7.9	68.5±7.0	70.7±5.7	68.3± 5.9	68.6±5.2	67.0±4.2*
T, °C	26.5±0.8	26.5±0.8	26.2±0.7	26.2±0.6	21.5± 0.9*	21.7± 0.9*	21.2±1.1*	21.2±1.1*
aH, mg/L	18.4±1.7	18.0±1.9	17.2±1.9	16.8±1.7	13.2±1.5*	12.9±1.5*	12.7±1.6*	12.3±0.9*
<b>Controlled heated humidification</b>								
rH, %	93.1±3.6	90.0±5.2	88.6±5.7	85.8±6.0	93.4±3.1	91.7±3.9	93.3±3.4	92.2±2.3
T, °C	26.9±0.7	26.8±0.7	26.3±0.8	26.1±0.7	23.3±0.8*	23.0±1.0*	22.5±1.1*	22.2±1.2*
aH, mg/L	23.7±1.4	22.8±1.4	21.8±1.8	20.9±1.6	19.2±0.9*	18.6±1.1*	18.4±1.3*	17.9±1.4*
<b>Controlled heated humidification with heated tube climate line</b>								
rH, %	82.8±8.2	81.3±6.7	82.5±5.9	81.1±5.3	77.7±4.2	75.2±3.1	77.3±2.6	77.0±3.2
T, °C	28.1±0.8	28.2±0.8	27.9±0.6	27.8±0.7	26.4±1.0*	26.2±1.0*	25.9±0.6*	25.7±0.5*
aH, mg/L	22.6±2.5	22.3±1.9	22.3±1.9	21.8±1.6	19.2±1.4*	18.4±1.2*	18.6±0.9*	18.3±1.1*

**Notes:** Data are presented as mean ± standard deviation. \**p* < 0.01 vs. summer.

## Subjective assessment

Patients were asked about their comfort after each experimental condition using a 5-item scale (0 = uncomfortable, 4 = comfortable). Patients were blinded to the condition. The highest comfort was achieved during the CL condition in the winter assessments, regardless of pressure and leakage (Figure 2).

## Discussion

In this study, differences in aH between the mask and lower respiratory tract were greatest in the presence of mask leak and the absence of HH. Use of HH that can take into account ambient temperature and humidity effectively increased mask aH in both summer and winter and compensated for the leakage, but was most effective during winter. Additional heated tubing did not increase aH above the level achieved with HH, but it did significantly increase temperature and decrease rH, and therefore had the advantage of keeping rH well below the dew point, preventing tube condensation.

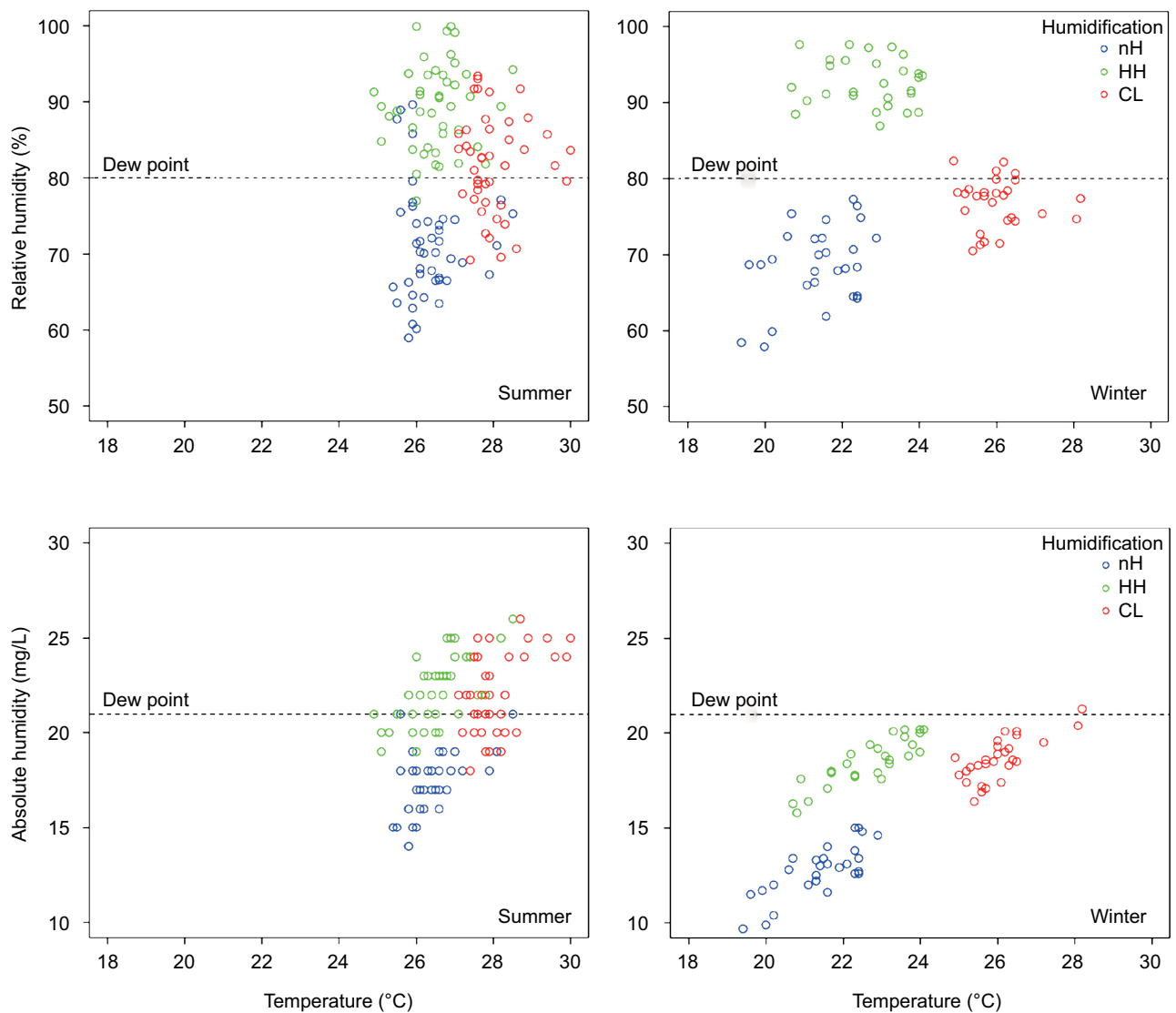
Our results showed marked variation in the performance of CPAP under summer and winter conditions. The seasonal variations might reflect what happens in different regions around the world. They could also provide one explanation for discrepancies between the results of previous studies looking at the role of humidification during CPAP.

It is our clinical experience that patients report more undesirable side effects from CPAP therapy during winter. The results of the current study do suggest that ambient

temperature and humidity are important factors influencing mask humidity. It would appear that leakage and lower ambient aH during the colder months can dehydrate the nasal mucosa. Heating and humidification conditions the inspired gases to body temperature and pressure saturated (BTPS) of 37°C and 100% rH, corresponding to an aH of 44.3 mg/L. This is thermodynamically neutral,<sup>15</sup> minimizes water loss and preserves the integrity of mucosal membrane function.<sup>16</sup>

A low ambient aH and T over a longer time can contribute to nasal dehydration and discomfort. We implemented a visual scale to display the patient's subjective comfort during the various conditions, certainly limited by the short period each condition was applied.

During CPAP at both pressure levels used in this study, CL significantly improved aH in the mask compared with no humidification, but not compared with HH. However, temperature in the mask was augmented by 2–3°C and rH decreased by > 10% when a heated tube was added compared with HH. Using an unheated tube during CPAP treatment at an ambient temperature of 15°C produced a temperature difference of about 4°C between the tube at the outlet of the humidifier and patient.<sup>17</sup> This represents a 10–15% increase in rH as the air stream cools down by > 4°C. Under these conditions, the dew point can be exceeded and condensation could form in the tube and mask. To avoid condensation in unheated tubes, the rH of gases at the humidifier should not exceed 80–85%. However, tube heating means that such



**Figure 1** Relationship between temperature and humidity.

**Notes:** Relative humidity (rH; %) and absolute humidity (aH, mg/L) dependent on temperature under winter and summer conditions during continuous positive airway pressure (CPAP) therapy with no humidification (nH; blue circles), standard heated humidification (HH; green circles) and heated tube humidification (CL; red circles). Data are combined for CPAP at 8 and 12 cmH<sub>2</sub>O, with and without leakage

**Abbreviation:** CL, climate line.

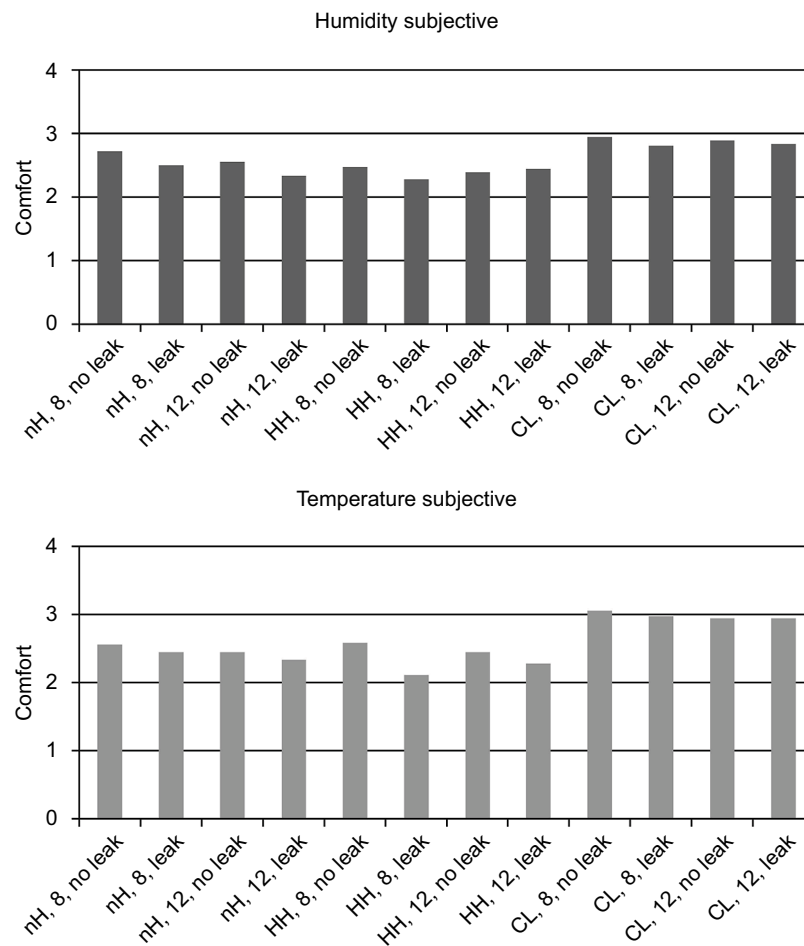
restrictions are not necessary and water condensation can be avoided.

In about one-fifth of OSA syndrome patients, the soft palate seal to separate the oral cavity from the pharynx is not complete and mouth flow can occur for several minutes.<sup>18</sup> During CPAP at 12 cmH<sub>2</sub>O, with and without leakage, rH in our study fell from 88.6 ± 5.7% to 85.8 ± 6.0%. In a study which simulated mouth leak, a decrease in rH from 82 ± 12% to 63 ± 9% was reported.<sup>10</sup> We assume that the experimental leakage flow in our study was below the order of magnitude that can occur with mouth breathing. The additional artificial leak in the nasal mask could almost be compensated for by

HH and aH was not reduced to any relevant extent compared with mask breathing without leakage.

Data from a previous study showed that during CPAP at 8 cmH<sub>2</sub>O without humidification, aH in the anterior turbinate region was at 15.3 ± 2.2 mg/L. When a nasal mask leak was added, the aH decreased by 1.5 mg/L.<sup>19</sup> In the current study, under the same CPAP conditions but a smaller nasal mask leak, aH in the mask was higher (18.4 mg/L) and the decrease associated with mask leak smaller (0.4 mg/L).

In intensive care medicine, aH values of > 23 mg/L are regarded as necessary to prevent drying of lower airways in intubated patients.<sup>20,21</sup> It is expected that lower humidity



**Figure 2** Overall subjective humidity and temperature evaluation during the applied pressure and leakage conditions.  
**Abbreviations:** nH, no humidity; HH, heated humidity; CL, climate line (0 = uncomfortable, 5 = comfortable).

values would be tolerated during nasal CPAP therapy because the humidification capacity of the nasal mucosa is maintained.<sup>22</sup> Richards et al found that maximum improvement of nasal resistance occurred at an aH of 21 mg/L.<sup>23</sup> In this study, mean aH during CPAP at 8 cmH<sub>2</sub>O without HH during winter was 13.2 mg/L, markedly below the 80% rH threshold. HH significantly increased mean aH to 19.2 mg/L during winter and to 23.7 mg/L during summer conditions.

A study found that although HH significantly improved nasopharyngeal symptoms, it did not influence a subject's willingness to continue CPAP, leading researchers to conclude that HH was not required at the initiation of CPAP therapy.<sup>24</sup> However, significant improvements in compliance have been documented with the use of HH.<sup>10</sup> In addition, there is a consistent relationship between humidification and improvement of nasal symptoms.<sup>7,9,24</sup>

The lack of a clear relationship between humidification and CPAP compliance is most likely because compliance is a multi-factorial issue, and a patient's requirement for humidification is also influenced by multiple factors including mask and mouth leak, ambient conditions, and CPAP

pressures.<sup>25</sup> It is also important to consider that previous studies used older models of humidifiers. Newer humidifier models with heated tubing have the ability to measure and adapt to ambient conditions and better optimize humidity delivery without causing condensation.

Our results show that the most effective humidification is achieved in summer conditions, with HH added to the circuit, no mask leak, and a heated tube. If patients do experience mask or mouth leak, or nasal symptoms, humidification should be offered. Subject age and the presence of chronic disease of the nasal mucosa should be taken into account as factors of the need for a heated humidifier.<sup>4,26</sup> If tube condensation is an issue during standard heated humidification then use of a heated tube is recommended.

## Limitations

One limitation of this study was the gap between study conditions due to experiments being conducted seasonally. Therefore, conditions may not have been identical for all subjects due to uncontrolled atmospheric conditions, and there may have been time biases. Creation of artificial

“winter” and “summer” conditions would have allowed the study to be conducted over a shorter timeframe. However, measurements during actual summer and winter should be more representative of reality in clinical practice.

## Conclusion

Winter conditions are associated with a clinically relevant reduction in aH in the mask during CPAP therapy, especially at higher pressures and in the presence of mask leak. The addition of heated humidification significantly increases aH inside the mask in both winter and summer (with and without leak). HH with heated tube raises temperature and decreases rH in the mask, and can be used to avoid condensation in the tube. The importance of seasonal conditions for CPAP delivery and use of HH need to be studied further and considered in future clinical trials.

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## Disclosure

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## References

- Engleman HM, Asgari-Jirhandeh N, McLeod AL, Ramsay CF, Deary IJ, Douglas NJ. Self-reported use of CPAP and benefits of CPAP therapy: a patient survey. *Chest*. 1996;109(6):1470–1476.
- Hoffstein V, Viner S, Mateika S, Conway J. Treatment of obstructive sleep apnea with nasal continuous positive airway pressure. Patient compliance, perception of benefits, and side effects. *Am Rev Respir Dis*. 1992;145(4 Pt 1):841–845.
- Pepin JL, Leger P, Veale D, Langevin B, Robert D, Lévy P. Side effects of nasal continuous positive airway pressure in sleep apnea syndrome. Study of 193 patients in two French sleep centers. *Chest*. 1995;107(2):375–381.
- Rakotonanahary D, Pelletier-Fleury N, Gagnadoux F, Fleury B. Predictive factors for the need for additional humidification during nasal continuous positive airway pressure therapy. *Chest*. 2001;119(2):460–465.
- Bachour A, Maasilta P. Mouth breathing compromises adherence to nasal continuous positive pressure therapy. *Chest*. 2004;126(4):1248–1254.
- Ruhle KH, Franke KJ, Domanski U, Nilius G. Quality of life, compliance, sleep and nasopharyngeal side effects during CPAP therapy with and without controlled heated humidification. *Sleep Breath*. 2011;15(3):479–485.
- Mador MJ, Krauz M, Pervez A, Pierce D, Braun M. Effect of heated humidification on compliance and quality of life in patients with sleep apnea using nasal continuous positive airway pressure. *Chest*. 2005;128(4):2151–2158.
- Neill AM, Wai HS, Bannan SP, Beasley CR, Weatherall M, Campbell AJ. Humidified nasal continuous positive airway pressure in obstructive sleep apnoea. *Eur Respir J*. 2003;22(2):258–262.
- Massie CA, Hart RW, Peralez K, Richards GN. Effects of humidification on nasal symptoms and compliance in sleep apnea patients using continuous positive airway pressure. *Chest*. 1999;116(2):403–408.
- Smith I, Lasserson TJ. Pressure modification for improving usage of continuous positive airway pressure machines in adults with obstructive sleep apnoea. *Cochrane Database System Rev*. 2009;4:CD003531.
- Martins De Araujo MT, Vieira SB, Vasquez EC, Fleury B. Heated humidification or face mask to prevent upper airway dryness during continuous positive airway pressure therapy. *Chest*. 2000;117(1):142–147.
- Nilius G, Domanski U, Franke KJ, Ruhle KH. Impact of a controlled heated breathing tube humidifier on sleep quality during CPAP therapy in a cool sleeping environment. *Eur Respir J*. 2008;31(4):830–836.
- Mortimore IL, Whittle AT, Douglas NJ. Comparison of nose and face mask CPAP therapy for sleep apnoea. *Thorax*. 1998;53(4):290–292.
- Chiumello D, Chierichetti M, Tallarini F, et al. Effect of a heated humidifier during continuous positive airway pressure delivered by a helmet. *Crit Care*. 2008;12(2):R55.
- Ryan SN, Rankin N, Meyer E, Williams R. Energy balance in the intubated human airway is an indicator of optimal gas conditioning. *Crit Care Med*. 2002;30(2):355–361.
- Williams R, Rankin N, Smith T, Galler D, Seakins P. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. *Crit Care Med*. 1996;24(11):1920–1929.
- Ruhle KH, Domanski U, Schroder M, Franke KJ, Nilius G. [Heated humidification during CPAP with and without tube insulation]. *Pneumologie*. 2010;64(5):316–319. German.
- Ruhle KH, Nilius G. Mouth breathing in obstructive sleep apnea prior to and during nasal continuous positive airway pressure. *Respiration*. 2008;76(1):40–45.
- Fischer Y, Keck T, Leiacker R, Rozsasi A, Rettinger G, Gruen PM. Effects of nasal mask leak and heated humidification on nasal mucosa in the therapy with nasal continuous positive airway pressure (nCPAP). *Sleep Breath*. 2008;12(4):353–357.
- Thomachot L, Viviani X, Lagier P, Dejode JM, Albanèse J, Martin C. Measurement of tracheal temperature is not a reliable index of total respiratory heat loss in mechanically ventilated patients. *Crit Care*. 2001;5(1):24–30.
- Wiest GH, Foerst J, Fuchs FS, Schmelzer AH, Hahn EG, Ficker JH. In vivo efficacy of two heated humidifiers used during CPAP-therapy for obstructive sleep apnea under various environmental conditions. *Sleep*. 2001;24(4):435–440.
- Rouadi P, Baroody FM, Abbott D, Naureckas E, Solway J, Naclerio RM. A technique to measure the ability of the human nose to warm and humidify air. *J Appl Physiol*. 1999;87(1):400–406.
- Richards GN, Cistulli PA, Ungar RG, Berthon-Jones M, Sullivan CE. Mouth leak with nasal continuous positive airway pressure increases nasal airway resistance. *Am J Respir Crit Care Med*. 1996;154(1):182–186.
- Yu CC, Luo CM, Liu YC, Wu HP. The effects of heated humidifier in continuous positive airway pressure titration. *Sleep Breath*. 2013;17(1):133–138.
- Ryan S, Doherty LS, Nolan GM, McNicholas. Effects of heated humidification and topical steroids on compliance, nasal symptoms, and quality of life in patients with obstructive sleep apnea syndrome using nasal continuous positive airway pressure. *J Clin Sleep Med*. 2009;5(5):422–427.
- Esquinas Rodriguez AM, Scala R, Soroksky A, et al. Clinical review: humidifiers during non-invasive ventilation – key topics and practical implications. *Crit Care*. 2012;16(1):203

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