Heated Humidification or Face Mask To Prevent Upper Airway Dryness During Continuous Positive Airway Pressure Therapy*

Maria Teresa Martins de Araújo, MS; Sérgio Barros Vieira, MD; Elisardo Corral Vasquez, PhD; and Bernard Fleury, MD

Study objectives: **The objectives of this study were (1) to evaluate the way in which nasal continuous positive airway pressure (CPAP) therapy influences the relative humidity (rH) of inspired air; and (2) to assess the impact on rH of the addition of an integrated heated humidifier or a full face mask to the CPAP circuitry.**

Design: **The studies were performed in 25 patients with obstructive sleep apnea syndrome receiving long-term nasal CPAP therapy and complaining of nasal discomfort. During CPAP administration, temperature and rH were measured in the mask either during a night's sleep for 8 patients or during a daytime study in which the effects of mouth leaks were simulated in 17 patients fitted with either a nasal mask (with or without humidification) or a face mask alone.**

Setting: **University hospital sleep disorders center.**

Measurements and results: **Compared with the values obtained with CPAP alone, integrated heated humidification significantly increased rH during the sleep recording, both when the mouth was closed (60 ± 14% to 81 ± 14%, $p < 0.01$) and during mouth leaks (43 ± 12% to 64 ± 8%, $p < 0.01$). During the daytime study, a significant decrease in rH was observed with CPAP alone. Compared with the values measured during spontaneous breathing without CPAP (80 ± 2%), the mean rH was 63 ± 9% ($p < 0.01$) with the mouth closed and 39 ± 9% ($p < 0.01$) with the mouth open. The addition of heated humidification to CPAP prevented rH changes when the mouth was closed (82 ± 12%), but did not fully prevent the rH decrease during simulation of mouth leaks (63 ± 9%) compared with the control period (80 ± 2%, $p < 0.01$). Finally, attachment of a face mask to the CPAP circuitry prevented rH changes both with the mouth closed (82 ± 9%) and with the mouth open (84 ± 8%).**

Conclusions: **These data indicate that inhaled air dryness during CPAP therapy can be significantly attenuated by heated humidification, even during mouth leaks, and can be totally prevented by using a face mask.** ***(CHEST 2000; 117:142–147)***

Key words: continuous positive airway pressure therapy; face mask; heated humidification; obstructive sleep apnea syndrome

Abbreviations: CPAP = continuous positive airway pressure; nCPAP = nasal continuous positive airway pressure; OSAS = obstructive sleep apnea syndrome; rH = relative humidity; T = temperature; TST = total sleep time

Nasal continuous positive airway pressure (nCPAP) has been used as standard therapy[1–5] for moderate-to-severe obstructive sleep apnea syndrome (OSAS). However, undesirable nasal effects, such as dryness, burning, and congestion have been described in patients using nCPAP.[6–9] The discomfort caused by breathing only through the nasal route leads some patients to progressively refuse the use of CPAP. Although several mechanisms may be potentially involved in the development of nasal discomfort, mouth leaks during the use of nCPAP seem to be particularly important[10–13] because they cause unidirectional inspiratory nasal airflow and progressive drying of the nasal mucosa. This mechanism is also known to promote the release of inflammatory mediators and can increase nasal airway resistance.[12,13]

*From the Physiological Sciences Graduate Program, Biomedical Center, Federal University of Espirito Santo (Ms. Martins de Araújo and Dr. Vasquez) and the Unit for Research in Sleep Disorders (UNI-SONO) of Espirito Santo (Dr. Barros Vieira), Vitoria, ES, Brazil, and the Unité de Sommeil, Service de Pneumologie, Hôpital Saint-Antoine (Dr. Fleury), Paris, France.

Supported by CAPES and Taema Inc., France.

Manuscript received January 4, 1999; revision accepted July 20, 1999.

Correspondence to: Bernard Fleury, MD, Unité de Sommeil, Service de Pneumologie, Hôpital Saint-Antoine, 184, Rue du Faubourg Saint-Antoine 75571, Paris, Cedex 12, France; e-mail: bernard.fleury@sat.ap-hop-paris.fr

Richards et al[12] recently demonstrated, in an experimental study in healthy subjects, that mouth leaks during nCPAP caused a marked increase in nasal resistance, which can be largely prevented by completely humidifying inspired air. Although no consensus has been reached concerning the optimal level of air humidification,[14–17] nCPAP therapy using heated humidification has been a standard technique. The use of this technique does not prevent all problems, as the addition of a humidifier increases the cost of nCPAP therapy and complicates the practical modalities (transport, cleaning, etc).[18] Solid clinical and experimental arguments are necessary, both for physicians and for health insurance bodies, to accept the regular use of additional humidification. However, to our knowledge, no data are available in the literature about modifications of the humidity of inspired air during nCPAP ventilation or after addition of heated humidification in patients with OSAS. Furthermore, in some cases, nCPAP therapy using heated humidification does not fully correct mucosal dehydration caused by mouth leaks in patients suffering from OSAS. Therefore, to resolve these problems, the use of face masks has been empirically proposed as an alternative method to prevent airway dryness during nCPAP in OSAS patients.[10,19,20]

The main objectives of this study, conducted in a group of patients with OSAS chronically treated by nCPAP and complaining of nasal discomfort, were to evaluate the consequences of nCPAP breathing on the humidity of inspired air and to measure the effect of additional heated humidification or face mask.

Materials and Methods

The studies were performed on 25 consecutive patients with a mean age of 56 ± 5 years and a mean body mass index of 30 ± 4 kg/m^2. All patients presented with moderate-to-severe OSAS with a mean apnea plus hypopnea index of 67 ± 29 events/h (range, 13 to 102 events/h). They were chronically treated with domiciliary nCPAP (33 ± 7 months). At a regular follow-up visit of their treatment, all of these patients reported nasal symptoms (chronic nasal obstruction, rhinitis, sneezing), making the daily use of nCPAP uncomfortable. Most of them presented with a condition that might promote mouth leaks (deviated nasal septum, 29%; chronic rhinitis or polyposis, 41%; uvulopalatopharyngoplasty, 24%). All patients gave their informed consent to participate in the study.

Relative humidity (rH) and temperature (T) of inspired air were measured using a specific transducer (Testor 171; Testo; Lenzkirch, Germany) inserted into the mask. Its range of accurate measurement was −20°C to +70°C for T and 2% to 98% for rH. The nCPAP machines used in these studies were fitted with a water bath supported by a plate (CP 95; Taema; Antony, France). This particular design allowed nCPAP with or without heated humidification. During heated humidification, the amount of water discharged by the machine into the airway was 8 $mL \cdot h^{-1} \cdot 10 \ cm \ H_2O^{-1}$.

Study 1 (Sleep Study)

The study was performed in eight male patients receiving long-term nCPAP therapy with a mean pressure of 12 ± 2 cm H_2O (range, 6 to 15 cm H_2O). rH and T were measured in these patients during full-night polysomnography with the positive pressure of the circuit set to the level used at home. nCPAP was administrated without humidification during the first half of the night (10:00 PM to 2:00 AM), and heated humidification was added during the second half of the night (2:00 AM to final awakening). Mouth leaks were identified by an oral thermistor. The cumulative duration of mouth leaks was calculated for each half of the night's recording and was reported as a percentage of total sleep time (TST) recorded during each half-night.

Study 2 (Daytime Study)

A daytime study was performed in another group of 17 patients (15 males and 2 females) receiving long-term treatment with effective nCPAP at an average pressure of 11 ± 2 cm H_2O (range, 6 to 15 cm H_2O).

In this daytime simulation, which lasted 3 h (2:00 PM to 5:00 PM), the effects of continuous positive airway pressure (CPAP) administered by nasal mask with or without heated humidification on rH and T were compared with the effects of a face mask.

The patients were instructed and instrumented for the following protocol: (1) spontaneous breathing for 30 min; (2) CPAP via a nasal mask (Taema) with the mouth closed for 30 min, followed by simulation of mouth leaks for 5 min; (3) CPAP with heated humidification and the mouth closed for 30 min, followed by simulation of mouth leaks for 5 min; and (4) CPAP via a face mask (Taema) with the mouth closed for 30 min, followed by simulation of mouth leaks for 5 min. The tubing was systematically replaced by a dry tube between experimental conditions 3 and 4.

The equipment was routinely checked before each study. rH and T were measured at the end of the hose, with and without heated humidification, to verify functioning of the humidifier.

Statistical Analysis

Results are reported as mean ± SD. In study 1, we used two-way analysis of variance with repeated measures comparing mean rH values and mean periods with mouth leaks, under the two conditions (CPAP with or without heated humidification), followed by the *post hoc* Tukey's test.[21] In study 2, mean rH values were compared between the various experimental conditions (mouth closed or open during CPAP, with or without heated humidification and spontaneous breathing) by analysis of variance for repeated measurements followed by the *post hoc* Tukey's test.[21] A probability value of 0.05 was considered significant.

Results

Equipment Verification

Systematic verification of the equipment showed that the mean rH, measured at the end of the hose, was always significantly higher with heated humidification than with CPAP alone (35 ± 4% vs 24 ± 3%, $p < 0.01$), with no significant variation of T (28 ± 1°C vs 28 ± 2°C).

Study 1

As illustrated in Figure 1 and summarized in Figure 2, the mean rH with nCPAP alone and with the mouth closed (60 ± 14%) during the first half of the night was significantly lower than that recorded during the second half of the night (81 ± 14%, $p < 0.01$), when nCPAP was administered with heated humidification. In these patients complaining of nasal discomfort, major mouth leaks were observed during nCPAP, representing 31 ± 27% of the TST (234 ± 42 min) during this first part of the night. A dramatic reduction of rH was observed during these periods of mouth leak, reaching an average rH of 43 ± 12%, compared with periods without leaks (60 ± 14%, $p < 0.01$).

Heated humidification decreased the consequences of mouth leaks by increasing rH to a comparable level to that observed with CPAP alone with the mouth closed (64 ± 8% and 60 ± 14%, respectively) and was associated with a decreased duration of mouth leaks (18 ± 23%, $p = 0.09$) of the TST (208 ± 36 min) during this second part of the night. These results are summarized in Figure 2.

The temperature threshold inside the mask in study 1 was 26 ± 2°C without heated humidification and 27 ± 2°C with heated humidification (room temperature, 25 ± 2°C), with no statistical differences between the groups.

Study 2

The results of this study are summarized in Figure 3. Compared with the control period of spontaneous breathing without nCPAP (80 ± 2%), rH was significantly decreased when the CPAP apparatus was turned on (63 ± 9%, $p < 0.01$) and markedly decreased when the patients were instructed to simulate mouth leaks (39 ± 9%, $p < 0.01$). The addition of heated humidification to CPAP prevented rH changes when the mouth was closed (82 ± 12%), but did not fully prevent the rH decrease during simulation of mouth leaks (63 ± 9%) compared with the control period (80 ± 2%, $p < 0.01$). When heated humidification in the nasal mask was replaced by attachment of a face mask to the CPAP apparatus, the rH decrease was totally prevented both with the mouth closed and during simulation of mouth leaks

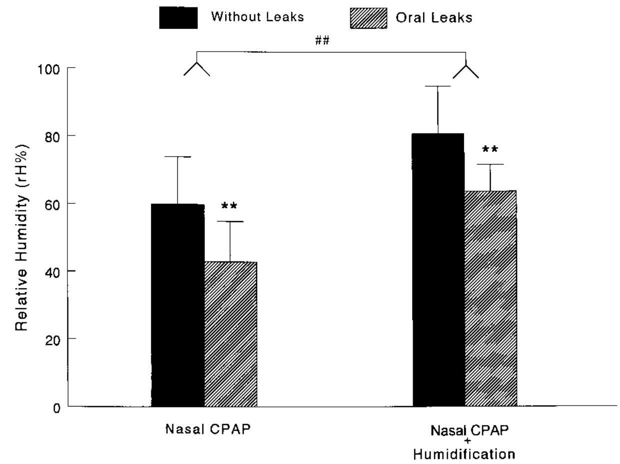

FIGURE 2. Nocturnal rH% mean values ± SD in eight patients with OSAS during nCPAP therapy with and without humidification. ** $p < 0.01$ compared with breathing in the CPAP circuitry without leaks. ## $p < 0.01$ compared with CPAP without humidification.

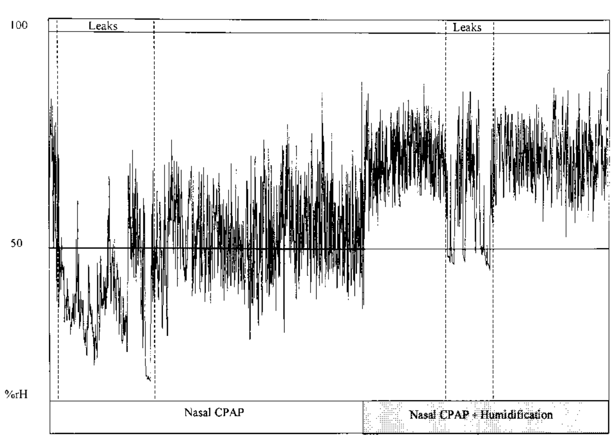

FIGURE 1. Typical recording obtained during sleep illustrating relative humidity (%rH) with nCPAP alone during the first part of the night (*left part of trace*) followed by nCPAP with heated humidification (*right part of trace*) during the second part of the night. The period of mouth leaks in each condition are indicated by vertical broken lines.

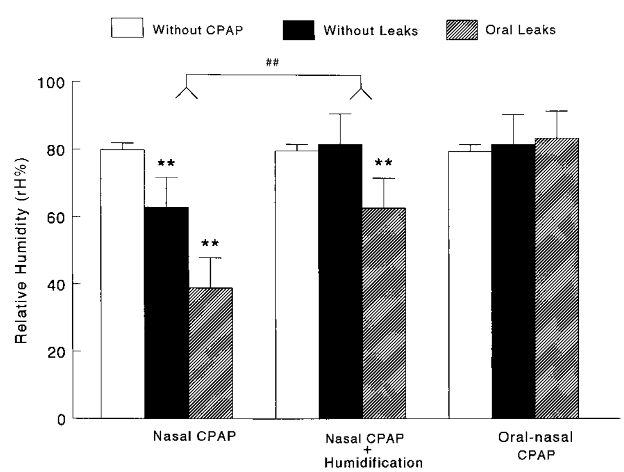

FIGURE 3. Daytime rH% mean values ± SD in 17 patients with OSAS, simulating mouth leaks in the nCPAP, with and without humidification and oral-nasal breathing alone. ** $p < 0.01$ compared with spontaneous breathing when the nasal mask was not connected to the CPAP machine. ## $p < 0.01$ compared with CPAP without humidification.

(82 ± 9% and 84 ± 8%, respectively) compared with control breathing without CPAP (80 ± 2%).

The temperature inside the masks in study 2 ranged from 28 ± 2°C to 30 ± 2°C, whereas room temperature was set at 25 ± 2°C, with no statistical differences between the groups.

Discussion

This study confirms that nCPAP therapy causes significant dryness of inspired air in patients with OSAS. We found that the rH decrease can be significantly attenuated by heated humidification of inspired air, even during periods of mouth leak. In addition, when CPAP therapy was administered by face mask, the rH decrease was totally prevented in patients with OSAS.

It has been clearly established that airway dryness largely accounts for nasal discomfort during nCPAP therapy.[9,10,12,13,18] In our patients complaining of nasal discomfort during nCPAP therapy, we found that the rH of nasal inspired air during nCPAP therapy decreased significantly during the night (study 1), particularly during mouth leaks, which represented an average of 31% of TST. The nasal mucosa has a considerable capacity to heat and humidify inspired air.[16,22–24] However, this capacity can be overwhelmed at high flow rates and particularly under conditions of unidirectional flow (mouth leaks) because the nasal mucosa usually recovers one third of the water delivered to the inspiratory airflow from the expiratory airflow.[12,16–19] Excessive drying of the nasal mucosa has also been shown to induce the release of vasoactive amines and leukotrienes.[22,23,25] These mediators increase superficial mucosal blood flow and engorgement of deeper capacitance vessels, leading to increased nasal resistance.[13] In turn, this increased nasal resistance could induce mouth breathing, creating a pathologic vicious circle. Richards et al[12] demonstrated this increased nasal resistance (up to 6 times the baseline value) during CPAP ventilation in normal subjects associated with deliberately created mouth leaks.[12]

A clinical consensus has been reached that nCPAP therapy with heated humidification can prevent or improve mucosal dehydration.[12] In our study, addition of a heated humidifier to the nCPAP circuitry during the second part of the night was able to compensate for the dehydration induced by nCPAP, by increasing the rH of inspired air during nasal ventilation to the levels observed during spontaneous breathing without nCPAP. However, when patients breathe through the mouth, correction of dehydration is incomplete, but rH is increased to a level comparable to that observed during nasal ventilation with nCPAP alone. Over the same period, the mean sleep time with mouth leaks was decreased by half. This reduction could be related to a reduction of nasal resistance by heated humidification. These data are in agreement with the results reported by Richards et al,[12] who observed a very significant attenuation of increased resistance after addition of heated humidification. This effect was essentially related to the increased rH of inspired air rather than a variation of the temperature of the gas. In our study, the temperature in the mask did not vary significantly after addition of the heated humidifier, probably because of heat loss along the tube between the CPAP machine and the mask.

As suggested by Richards et al,[12] mouth leaks occurring frequently during the night may lead to a gradual increase in baseline nasal resistance. Our choice to systematically add humidification during the second part of the night may have favored the persistence of an abnormal elevation of resistance, facilitating some of the residual mouth leaks observed. In addition, this study did not comprise any exclusion criteria known to cause an increase in baseline nasal resistance, such as allergic rhinitis, polyposis, or deviated nasal septum.

These observations of persistent dehydrating mouth leaks despite heated humidification prompted us to evaluate the use of an alternative approach (face mask) during nCPAP therapy in patients with OSAS. In study 2, we compared the rH of inspired air in a group of patients with moderate-to-severe OSAS under three different simulated conditions: (1) nCPAP alone, (2) heated humidification, and (3) use of a face mask. The importance of the current protocol is that it enabled us to simulate the effects of mouth leaks on rH during sleep. The mean amplitude of the rH decrease was identical to that observed during the night, during phases of mouth breathing, which lasted < 5 five consecutive minutes in the majority of patients. As previously observed in the group of patients with OSAS in study 1, nCPAP plus heated humidification substantially increased the rH during mouth leaks, compared with the use of nCPAP alone, but the rH did not reach the levels recorded during spontaneous breathing. In contrast, use of a face mask during CPAP therapy avoided all dehydration of the respiratory tract. We propose that the face mask maintains the saturated gas returned during the expiratory phase and therefore counterbalances the difference between dry inspired gas and saturated expired gas at each cycle, establishing an optimal airway humidity gradient. The dynamic equilibrium of heat and moisture exchange in the upper airway is preserved during expiration, thereby maintaining normal mucosal function and airway patency in patients with OSAS who have mouth leaks.[17,24] Mortimore et al[19] recently reported that the use of a full face mask significantly reduced complaints of dry mouth and nose during CPAP therapy in 20 patients with OSAS.

Unfortunately, despite the advantages of the full mask to reduce nasal symptoms, the nasal mask was considered to be more comfortable than the face mask by the patients enrolled in the trial conducted by Mortimore et al.[19] This discomfort counterbalanced the benefits of complete humidification of inspired air and limited compliance with CPAP therapy of the patients using the face mask.[20] Daily use of a full mask was proposed to the 17 patients in whom it was tested during this study. All reported unpleasant dryness during ventilation with mouth leaks, which was markedly reduced by heated humidification and completely eliminated by face mask. However, only two of these patients accepted long-term use of the face mask, as the others found it too uncomfortable, particularly because of a poor fit with the contours of the face, generating leaks requiring painful tightening of the straps. All patients have now been placed on heated humidification at home. Nasal discomfort was eliminated in 15 of 17 patients. We did not evaluate the possible repercussions of addition of the heated humidifier in terms of compliance with treatment in these patients. However, in a previous study, we reported a significant increase of daily compliance (from an average of 3.0 to 5.5 h) after addition of heated humidification in patients with OSAS complaining of nasal discomfort.[26] The objective efficacy of heated humidification reported in the present study and the resulting improved compliance with treatment appear to justify the prescription of heated humidification in patients complaining of nasal discomfort, despite the additional financial cost, which can currently be estimated to represent 40% of the cost of a nCPAP machine.

In summary, we have demonstrated that heated humidification can prevent or lessen dehydration of inspired air during nCPAP therapy in patients with OSAS complaining of nasal symptoms, particularly when they suffer from a condition likely to promote mouth leaks. A face mask could also constitute a reasonable alternative for the treatment of mouth-breathing patients with OSAS, but manufacturers need to improve the humidification capacity of the heated humidifier or the design of commercial face masks.

ACKNOWLEDGMENT: We thank Mr. Thierry Cornen and Mr. Fabien Curron for technical assistance and Ms. Yolande Dumet for her help in manuscript preparation.

References

1 Sullivan CE, Issa FG, Berthon-Jones M, et al. Reversal of obstructive sleep apnea by continuous positive airway pressure applied through the nares. Lancet 1981; 1:862–865

2 Sanders MH, Gruendl CA, Rogers RM. Patient compliance with nasal CPAP therapy for sleep apnea. Chest 1986; 90:330–333

3 Rauscher H, Popp W, Wanke T, et al. Acceptance of CPAP therapy for sleep apnea. Chest 1991; 100:1019–1023

4 Nino-Murcia G, McCann CC, Bliwise DL, et al. Compliance and side effects in sleep apnea patients treated with nasal continuous positive airway pressure. West J Med 1989; 150:165–169

5 Fleury B, Rakotonanahary D, Tehindrazanarivelo AD, et al. Long-term compliance to continuous positive airway pressure therapy (nCPAP) set up during a split-night polysomnography. Sleep 1994; 17:512–515

6 Hoffstein V, Viner S, Mateika S, et al. Treatment of obstructive sleep apnea with nasal continuous positive airway pressure: patient compliance, perception of benefits, and side effects. Am Rev Respir Dis 1992; 145:841–845

7 Kribbs NB, Pack AI, Kline LR, et al. Objective measurement of patterns of nasal CPAP use by patients with obstructive sleep apnea. Am Rev Respir Dis 1993; 147:887–895

8 Engleman HM, Martin SE, Douglas NJ, et al. Compliance with CPAP therapy in patients with the sleep apnea/hypopnea syndrome. Thorax 1994; 49:263–266

9 Pepin JL, Leger P, Veale D, et al. Side effects of nasal continuous positive airway pressure in sleep apnea syndrome: study of 193 patients in two French sleep centers. Chest 1995; 107:375–381

10 Prosise GL, Berry RB. Oral-nasal continuous positive airway pressure as a treatment for obstructive sleep apnea. Chest 1994; 106:180–186

11 Ohki M, Usui N, Kanazawa H, et al. Relationship between oral breathing and nasal obstruction in patients with obstructive sleep apnea. Acta Otolaryngol 1996; 523(suppl):228–230

12 Richards GN, Cistulli PA, Ungar G, et al. Mouth leak with nasal continuous positive airway pressure increases nasal airway resistance. Am J Respir Crit Care Med 1996; 154:182–186

13 Hayes MJ, McGregor FB, Roberts DN, et al. Continuous nasal positive airway pressure with a mouth leak: effect on nasal mucosal blood flux and nasal geometry. Thorax 1995; 50:1179–1182

14 Branson RD. Humidification of inspired gases during mechanical ventilation. Respir Ther 1991; 3:55–66

15 American Association for Respiratory Care. Consensus statement on the essentials of mechanical ventilators. Respir Care 1992; 36:1000–1008

16 Shelly MP, Lloyd GM, Park GR. A review of the mechanisms and methods of humidification of inspired gases. Intensive Care Med 1988; 14:1–9

17 Miyao H, Hirokawa T, Miyasaka K, et al. Relative humidity, not absolute humidity, is of great importance when using a humidifier with a heating wire. Crit Care Med 1992; 20:674–679

18 Strumpf DA, Carlisle CC, Beadles SC, et al. Alternative methods of humidification during use of nasal CPAP. Respir Care 1990; 35:217–221

19 Mortimore IL, Whittle AT, Douglas NJ. Comparison of nose and face mask CPAP therapy for sleep apnoea. Thorax 1998; 53:290–292

20 Sanders MH, Kern NB, Stiller RA, et al. CPAP therapy via oronasal mask for obstructive sleep apnea. Chest 1994; 106:774–779
21 Snedecor GW, Cochran WG. Statistical methods. 8th ed. Ames, IA: Iowa State University Press, 1989
22 Ingelstedt S, Ivstam S. Study of the humidifying capacity of the nose. Acta Otolaryngol 1951; 39:286–290
23 Cole P. Modification of inspired air. In: Proctor DF, Anderson IB, eds. The nose. Oxford, UK: Elsevier Biomedical, 1982; 350–375
24 Williams R, Rankin N, Smith T, et al. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. Crit Care Med 1996; 24:1920–1929
25 Togias A, Proud D, Lichtenstein LM, et al. The osmolality of nasal secretions increases when inflammatory mediators are released in response to inhalation of cold dry air. Am Rev Respir Dis 1988; 137:625–629
26 Rakotonanahary D, Pelletier-Fleury N, Fleury B. Predictive factors for an additional humidification during nCPAP therapy [abstract]. Am J Respir Crit Care Med 1998; 157:A345

1