11 Practice of Humidification During Noninvasive Mechanical Ventilation (NIV): Determinants of Humidification Strategies

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Abbreviations

AH	Absolute humidity
ARF	Acute respiratory failure
BIPAP	Bilevel airway pressure
COPD	Chronic obstructive pulmonary disease
CPAP	Continuous positive airway pressure
CPE	Cardiac pulmonary edema
ETI	Endotracheal intubation
FEV_1	Forced expiratory volume in the first second
H1N1	H1N1 flu virus
HME	Heat and moisture exchanger
HWH	Heated wire humidifiers
ICU	Intensive care unit
IMV	Invasive mechanical ventilation
MV	Mechanical ventilation

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NAWR	Nasal airway resistance
NIV	Noninvasive mechanical ventilation
RH	Relative humidity
SAOS	Sleep apnea obstructive syndrome
SARS	Severe acute respiratory syndrome
VAP	Ventilator-associated pneumonia
VT	Volume tidal

11.1 The Development of the NIV and Humidification

The provision of heat and humidity during mechanical ventilation (MV) is a standard of care worldwide [1]. There is an international consensus on the importance of humidification during invasive mechanical ventilation. The two humidification methods used during invasive MV are: the heated humidifier and the heat-and-moisture exchange (HME).

Noninvasive mechanical ventilation (NIV) is increasingly used in intensive care units (ICU) and emergency departments. Currently, it is the standard of care in the treatment of acute exacerbation of chronic obstructive pulmonary disease (COPD), acute cardiogenic pulmonary edema (CPE), and immunocompromised patients [2, 3]. Furthermore, NIV is available for home use for patients with sleep-related breathing disorders and chronic respiratory failure.

The routine use of humidification during NIV is controversial. There is no consensus statement defining the indications, patient selection, device selection, etc. The literature provides some evidence in terms of improving patient comfort and some other physiological parameters. However, well-designed studies are necessary to provide clear evidence to support or discourage the use of humidification in NIV [4, 5].

This chapter focuses on the use of humidification in NIV especially when applied to patients with acute respiratory failure (ARF). The physiological aspects of humidification have been covered thoroughly in other chapters of this book. The available data in the literature will be reviewed in order to develop an adequate strategy for the use of humidification in NIV.

11.2 Humidification in NIV

The available data in this field are very scant. In addition, the published studies have a number of limitations that make their interpretation and the development of a clear approach for humidification difficult.

The following challenges are facing the development of a standard approach to humidification in NIV:

1. Absence of a consensus statement in this regard despite the availability of statements and recommendations that guide the overall use of NIV [2, 4].
2. Clinical and bench studies do not always reflect the actual practice because of the interaction of many variables in real patients [6–8].

3. No comprehensive survey has been conducted among practitioners [5].
4. Finally, the development of proper clinical practice guidelines depends to a large extent on the availability of randomized clinical trials in well-defined populations [9, 10]. Such data are missing at this stage.

Initial reports that alerted practitioners to the importance of humidification in patients on NIV came from observational studies conducted on patients with ARF. Those reports drew the attention of practitioners to the beneficial effects of applying humidification in NIV and the potential complications of inhaling dry gas [11–13].

The international consensus document on NIV published in 2001 did not thoroughly address the use of humidification in NIV because of insufficient data at that time, especially in applying NIV to patients with ARF [2]. In the last decade, there has been a major technological breakthrough in the manufacturing of humidifiers and a better understanding of how to incorporate these new humidifiers into the conventional devices of NIV. For example, with some of these humidifiers, some potential beneficial effects were described on the control of hypercapnia and work of breathing (WOB) [13]. Furthermore, a form of agreement that humidification of inspired gases should be a standard of care has begun to evolve among specialists [1]. Since 2005, a growing number of studies on the use of humidification in NIV have been published. In this chapter, we discuss the international survey we conducted in 2008 in 15 hospitals to explore the practice of incorporating humidification in NIV [5]. This chapter focuses on three key questions:

5. Who will benefit from humidification?
6. When to apply humidification?
7. How to incorporate humidification into NIV?

11.3 Humidification in Early/Short-Term Use of NIV

NIV has been accepted worldwide as a standard of care for a number of respiratory disorders with clear indications in the emergency or home settings [1]. However, the practice of using humidification with NIV is not practiced routinely. Today, we understand that NIV may adversely influence the normal humidification system in the body and hence decrease moisture of the inspired gas [4].

Evaluating the response of the upper and lower airways in asthmatic patients hyperventilating cold air and breathing through the mouth demonstrated a decrease in FEV1 and an increase in nasal resistance [4]. Additionally, controlled asthmatics who are mouth breathers are also found to have an increase in nasal airway resistance [14]. Perhaps in obstructive crisis, when patients breathe through the mouth, insufficient moisture can play an important role, though this has yet to be documented.

One of the objectives of early use of humidification during noninvasive ventilation is to enhance tolerance and subsequent compliance with NIV. Discomfort or intolerance of NIV devices can result from different factors. Dryness of the mucous

membranes is one of the major contributing factors. Clinical trials are needed to determine whether the application of humidification can improve tolerance and enhance compliance to NIV [11, 14].

Humidification requirements should be tailored to the clinical characteristics and needs of each patient. Therefore, it is necessary to consider conditions that influence the moisture of the airway such as diseases of the respiratory mucosa, nasal septum deviation, medications, ventilator setting, and types of interfaces [14]. Nasal masks promote mouth leaks and therefore high unidirectional nasal flow, which results in increased nasal resistance and mouth opening, which in turn perpetuate mouth leak [14, 15]. Heated humidification as discussed in other chapters of this book acts by increasing the relative humidity (RH) of the air, reducing nasal resistance, and possibly increasing adherence to NIV.

The available literature lacks large-scale studies that evaluate the use of humidification for early and acute application of NIV. In clinical practice, it has been observed that some complications have developed in the absence of humidification and have contributed directly or indirectly to NIV failure and difficulties in endotracheal intubation [16]. The literature also lacks information about the frequency of this problem in patients with ARF on NIV. However, the application of a heated humidifier has proven to be useful and safe in the control of associated symptoms such as mucosal dryness, and therefore may contribute to improved comfort and compliance, especially in patients with chronic stable respiratory diseases [17, 18]. The development of an algorithm that stratifies patients into different risk groups is essential. Knowledge of the above-mentioned information and training and experience of the medical team applying the NIV are necessary to create a successful algorithm that can provide proper NIV application strategies.

Some factors that can influence the decision for early use of humidification are:

1. *Cost-effectiveness*:

   The economic aspect and the cost of implementing humidification strategies is another considerable factor that can influence the selection of the humidifier to treat patients on NIV. A status of balance between the cost and the benefits of humidification should be achieved particularly when considering short-term use of NIV [18]. With regard to invasive mechanical ventilation (IMV), clinical aspects such as the duration of IMV, the increased risk of developing ventilator-associated pneumonia and weaning difficulties are well identified and important outcomes that favor the routine and early use of humidification [19, 20]. Unfortunately, in the case of NIV such clinical outcomes are not well identified and studied. Nevertheless, the development of complications as a result of not using proper humidification in patients with ARF treated with NIV will add to the cost of ARF treatment. Furthermore, failure of NIV for any reason will lead to a more costly intervention, such as endotracheal intubation. Therefore, it would be reasonable to identify patients on NIV at a moderate to high risk of developing complications if not using humidification and provide them with early humidification. One of the serious complications is the difficulty experienced with endotracheal intubation, which is attributed to the dryness of the upper airway mucosa [5, 8, 16, 21].

2. *Type of respiratory disease*:
   The use of an early humidification strategy is required in respiratory failure secondary to some respiratory diseases, such as COPD and asthma, where the introduction of humidification has shown favorable effects [12, 14].
3. *Type of ARF*:
   When discussing the available data pertaining to humidification in NIV, we have to categorize ARF into hypoxemic and hypercapnic. In patients with hypoxemic ARF, data supporting the use of humidification are available for those requiring FiO_2 greater than 0.60 and those who are expected to require a prolonged use of NIV (>2 h) [15, 16].
   In patients with hypoxemic ARF, data supporting the use of humidification are available for those requiring FiO_2 greater than 0.60 and those who are expected to require a prolonged use of NIV (>2 h) [22] and characteristics of bronchial secretions [12, 23].
4. *Ventilatory parameters*:
   The use of ventilatory parameters influences moisture loss. The higher the tidal volume (V_T) and the higher the peak inspiratory flow rate, as with the NIV-CPAP systems, the greater the moisture loss is. Therefore, these physical conditions should be considered when applying NIV. Early institution of humidification reduces the effects of V_T and flow rate on humidity [12, 24].
5. *Bronchial secretion clearance*:
   The rheological property of the viscosity of bronchial secretions is an important determinant of the early humidification strategy, especially in critically ill patients, as discussed in other chapters of this book [25]. The loss of these characteristics leads to retention of the bronchial secretions, especially in the distal airways of the bronchial system that are difficult to draw from, and results in increased airway resistance, impaired gas exchange, and airway obstruction, etc. [6, 15, 21]. The early combination of proper humidification with cough-assist techniques is useful and can improve the outcome of the NIV. Other factors that can encourage an early implementation of humdification include: older age, increased nasal resistance, mucociliary dysfunction, medication that can cause dehydration of the mucosa, chronic nasal or respiratory diseases, mouth breathing, and bronchial hypersecretion, especially if associated with COPD or bronchiectasis [21, 23, 25]. Despite the long list of proposed benefits of humdification in NIV, it is usually used without humdification, and controversy still exits regarding humidification efficacy [1, 4]. More studies are needed to document the benefits of humidification in patients with ARF who require NIV. Although we still need more evidence, the application of humidification in the above-discussed conditions is encouraged.

Contrarily, some factors deter the routine use of humidification in NIV. These factors include:

1. Absence of a consensus on the criteria needed to identify the appropriate candidates and indications for early humidification use.
2. In some cases, the humidifier model used can induce asynchronization problems via different mechanisms [6, 13, 19, 26, 27]:
   I. Increasing the largest dead space,
   II. Increasing work of breathing,

III. Rebreathing problems,
IV. Causing a drop in inspiratory positive pressure.

3. Humidifier use may increase the cost of treatment with NIV [18].
4. Concerns with cross-infection may limit the use of humidifiers. Heat-moisture exchange (HME) use for short-term NIV in patients with ARF is associated with less cross-infection [28]. The heated humidifier may carry a greater risk of spreading aerosols of respiratory viral infections (SARS, H1N1) or *Mycobacterium tuberculosis*. Nevertheless, the currently published work of the International Network Group, which was analyzed during the H1N1 pandemic, did not demonstrate such an association [29]. However, with the long-term use of NIV at home for OSAS, a potential risk of colonization and infection was described [30].

11.4 Current Practice of Humidification in NIV

1. *Hospital organization*.
   In some institutions, the decision to use humidification in NIV depends on the setting where the NIV is applied, such as emergency departments, intensive care units, or outpatient settings. Humidification is recommended when high-flow NIV-CPAP is used in patients at high risk even if it is going to be used for a short time [24]. Such practice is mostly seen in critically ill patients in the medical ICU or postoperative recovery units [31].
2. *Geographical data*.
   The differences in humidity among countries would suggest a variation in the practice of humidification use. Nevertheless, the International Survey in Humidification Practice did not suggest these geographical factors to be important in the practice of humidification [5]. The European Survey of Noninvasive Ventilation Practices showed that humidification practice is common in Europe [3].

11.5 The International Survey of Humidification Practice

Surprisingly, no epidemiological survey has been conducted analyzing the practice of NIV humidification and its effects on short-term outcomes that can guide humidification practice [3, 5, 31]. Below is a summary of the available data.

1. *Types of humidifiers*
   There are no data to support one humidification system over the other or to demonstrate the superiority of one over the other in terms of hygrometry efficacy or absolute humidity. The selection of the humidification system depends on other factors such as the interface (nasal, facial, helmet) [32], and the type of mechanical ventilator (home mechanical ventilator, high flow CPAP systems or ICU mechanical ventilators) [3, 5, 24, 31].
   i. *Heated humidifier (HH)*
   The HH acts as an active system to increase the AH to acceptable levels with a minimal effect on the set inspiratory positive airway pressure (IPAP) (on average

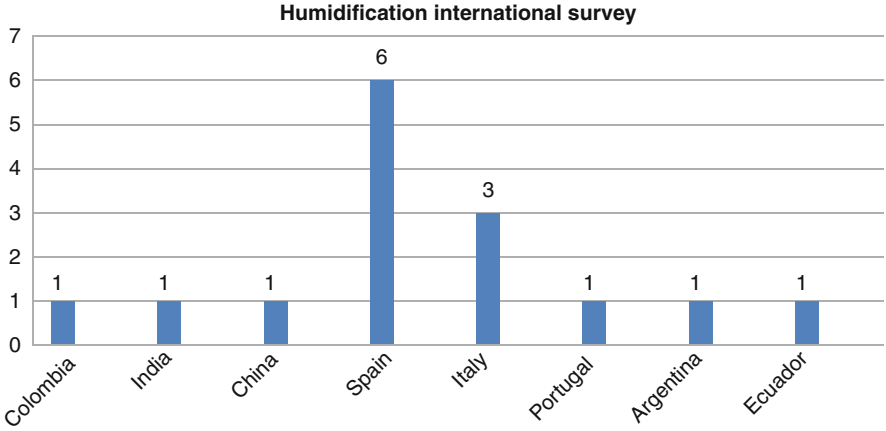

Fig. 11.1 Countries participating in the International Survey-NIV

IPAP can decrease by a value of 0.5–1 cmH_2O) [20]. Currently HHs are preferred when the air is dry and cold with retention of bronchial secretions [26]. Unidirectional flow causes nasal mucosal dryness, promotes the release of inflammatory mediators, and increases nasal resistance [15, 21]. The HH increases the RH in the air, reduces nasal airway resistance, and may increase adherence to the NIV compared to HMEs [6, 8, 9, 17, 26, 33].

ii. *Heat and moisture exchanger (HME)*

As defined in other chapters, the HME acts by conserving moisture endogenously in the breathing circuit and is used when the patient has sufficient capacity to maintain AH of the inspired air. It is recommended to be applied early, but not recommended with all types of interfaces (nasal mask or face mask). They are ideal for the helmet system. Chanques et al. found that the humidifiers most commonly used are HMEs (52%), followed by HHs (26%), both (4%), and neither (19%) in postoperative resuscitation units.

In our international survey, we analyzed the information from 15 hospitals including information on 1635 patients who had been treated with NIV in 2008 [5] (Fig. 11.1). When the results were analyzed in relation to the humidification system used, we found that the heated wire humidifier (HWH) was used most frequently (46.6%). No differences between countries, types of hospital settings, or acute care units were observed. This is different from the results of Chanques et al., who analyzed data collected from post-surgical observation units [31].

2. *Humidifier availability*.

Humidifier availability is influenced by several factors, including hospital area (acute care units, general wards, or out-patient setting), the type of ARF, the type of ventilator and interface used, and the number of patients treated simultaneously with NIV. The above are factors that determine the availability and type of humidifier to be selected [3, 5].

3. *Protocols of humidification*.

In our survey, we observed that 40% of the surveyed hospitals do not have written protocols to guide the use of humidification in NIV. The utilization of

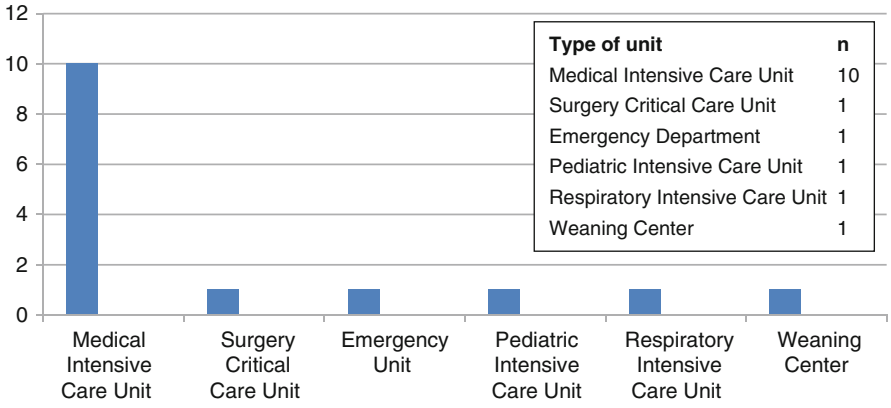

Fig. 11.2 Type of units in the NIV humidification practice survey

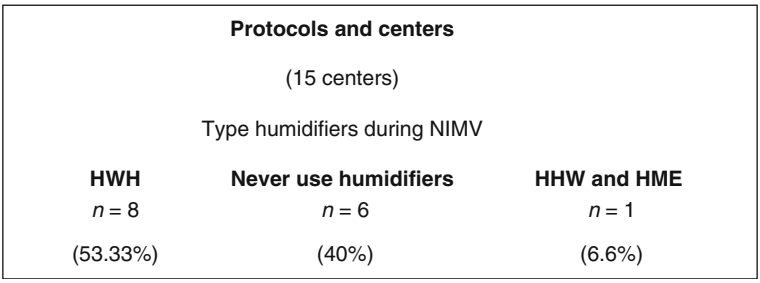

Fig. 11.3 Protocols of humidification practice and type of humidifiers used. *HWH* heated wire humidifier, *HME* heat and moisture exchanger. Models HWH used: hwh –fp-mru830-1; hwh- fp-(*mr730, and others models = 1); hwp-fp= (410s, 810s) = 1. FP = fisher@paykel models

humidification in NIV seems to depend to a large extent on the practitioner's experience and preference. There are no large epidemiological studies to analyze other factors associated with humidification and response to NIV. [5] (Figs. 11.1, 11.2 and 11.3).

4. *Education*.
   Education is of paramount importance to achieve proper implementation and optimal results of humidification in NIV [26]. Our survey revealed that there was no formal training or education for NIV and humidification in the surveyed hospitals.

11.6 Conclusion

There are no large epidemiological studies to determine the best strategy for humidification in NIV. However, based on the available data, the best strategy to ensure proper application of humidification in NIV is to first indentify the factors that may affect humidification and enhance moisture loss in patients with ARF, and then to apply the proper humidification system that suits each case based on the patient's

clinical condition, the ventilator parameters, and the interface used. Early application of humidification may benefit patients with hypoxemic respiratory failure or obstructive pulmonary diseases, and patients on high-flow CPAP systems, or who need prolonged use of NIV. Multi-center studies with large numbers of patients are needed to identify the patient groups who are likely to benefit from the addition of humdification to NIV therapy and to assess the effect of humidification on adherence to NIV, and its effect on different outcome measures.

References

1. Branson RD (2006) Humidification of respired gases during mechanical ventilation: mechanical considerations. Respir Care Clin N Am [Review] 12(2):253–261
2. Evans TW (2001) International Consensus Conferences in Intensive Care Medicine: non-invasive positive pressure ventilation in acute respiratory failure. Organised jointly by the American Thoracic Society, the European Respiratory Society, the European Society of Intensive Care Medicine, and the Societe de Reanimation de Langue Francaise, and approved by the ATS Board of Directors, December 2000. Intensive Care Medicine. [Consensus Development Conference Review]. 27(1):166–178
3. Crimi C, Noto A, Princi P, Esquinas A, Nava S (2010) A European survey of noninvasive ventilation practices. Eur Respir J: Official Journal of the European Society for Clinical Respiratory Physiology 36(2):362–369
4. Branson RD, Gentile MA (2010) Is humidification always necessary during noninvasive ventilation in the hospital? Respir Care 55(2):209–216, discussion 16
5. Esquinas A, Nava S, Scala R, Carrillo A, González G, Humivenis Working Group (2008) Humidification and difficult endotracheal intubation in failure of noninvasive mechanical ventilation (NIV). Preliminary results. Am J Respir Crit Care Med 177:A 644
6. Jaber S, Chanques G, Matecki S, Ramonatxo M, Souche B, Perrigault PF et al (2002) Comparison of the effects of heat and moisture exchangers and heated humidifiers on ventilation and gas exchange during non-invasive ventilation. Intensive Care Med 28(11):1590–1594
7. Lellouche F, Maggiore SM, Lyazidi A, Deye N, Taille S, Brochard L (2009) Water content of delivered gases during non-invasive ventilation in healthy subjects. Intensive Care Med 35(6):987–995
8. Martins De Araujo MT, Vieira SB, Vasquez EC, Fleury B (2000) Heated humidification or face mask to prevent upper airway dryness during continuous positive airway pressure therapy. Chest 117(1):142–147
9. Ruhle KH, Franke KJ, Domanski U, Nilius G (2010) Quality of life, compliance, sleep and nasopharyngeal side effects during CPAP therapy with and without controlled heated humidification. Sleep Breathing May 26
10. Worsnop CJ, Miseski S, Rochford PD (2010) Routine use of humidification with nasal continuous positive airway pressure. Intern Med J [Research Support, Non-US Gov't] 40(9):650–656
11. Nava S, Ceriana P (2004) Causes of failure of noninvasive mechanical ventilation. Respir Care 49(3):295–303
12. Wood KE, Flaten AL, Backes WJ (2000) Inspissated secretions: a life-threatening complication of prolonged noninvasive ventilation. Respir Care 45(5):491–493
13. Lellouche F, Maggiore SM, Deye N, Taille S, Pigeot J, Harf A et al (2002) Effect of the humidification device on the work of breathing during noninvasive ventilation. Intensive Care Med 28(11):1582–1589
14. Nava S, Navalesi P, Gregoretti C (2009) Interfaces and humidification for noninvasive mechanical ventilation. Respir Care 54(1):71–84
15. Richards GN, Cistulli PA, Ungar RG, Berthon-Jones M, Sullivan CE (1996) Mouth leak with nasal continuous positive airway pressure increases nasal airway resistance. Am J Respir Crit Care Med 154(1):182–186

16. Carrillo E-A, González G, Humivenis Working Group (2008) Absolute humidity variations with a variable inspiratory oxygenation fraction in noninvasive mechanical ventilation (NIV). A pilot study. Am J Respir Crit Care Med 177:A 644
17. Mador MJ, Krauza M, Pervez A, Pierce D, Braun M (2005) Effect of heated humidification on compliance and quality of life in patients with sleep apnea using nasal continuous positive airway pressure. Chest 128(4):2151–2158
18. Nava S, Cirio S, Fanfulla F, Carlucci A, Navarra A, Negri A et al (2008) Comparison of two humidification systems for long-term noninvasive mechanical ventilation. Eur Respir J 32(2):460–464
19. Siempos II, Vardakas KZ, Kopterides P, Falagas ME (2007) Impact of passive humidification on clinical outcomes of mechanically ventilated patients: a meta-analysis of randomized controlled trials. Crit Care Med [Comparative Study Meta-Analysis] 35(12):2843–2851
20. Girault C, Breton L, Richard JC, Tamion F, Vandelet P, Aboab J et al (2003) Mechanical effects of airway humidification devices in difficult to wean patients. Crit Care Med [Clinical Trial Comparative Study Randomized Controlled Trial] 31(5):1306–1311
21. Miyoshi E, Fujino Y, Uchiyama A, Mashimo T, Nishimura M (2005) Effects of gas leak on triggering function, humidification, and inspiratory oxygen fraction during noninvasive positive airway pressure ventilation. Chest 128(5):3691–3698
22. Cinnella G, Giardina C, Fischetti A, Lecce G, Fiore MG, Serio G et al (2005) Airways humidification during mechanical ventilation. Effects on tracheobronchial ciliated cells morphology. Minerva Anestesiol [Comparative Study Randomized Controlled Trial] 71(10):585–593
23. Nakagawa NK, Macchione M, Petrolino HM, Guimaraes ET, King M, Saldiva PH et al (2000) Effects of a heat and moisture exchanger and a heated humidifier on respiratory mucus in patients undergoing mechanical ventilation. Crit Care Med [Clinical Trial Comparative Study Randomized Controlled Trial Research Support, Non-US Gov't] 28(2):312–317
24. Poulton TJ, Downs JB (1981) Humidification of rapidly flowing gas. Crit Care Med 9(1):59–63
25. Nakagawa NK, Franchini ML, Driusso P, de Oliveira LR, Saldiva PH, Lorenzi-Filho G (2005) Mucociliary clearance is impaired in acutely ill patients. Chest 128(4):2772–2777
26. Holland AE, Denehy L, Buchan CA, Wilson JW (2007) Efficacy of a heated passover humidifier during noninvasive ventilation: a bench study. Respir Care 52(1):38–44
27. Boyer A, Vargas F, Hilbert G, Gruson D, Mousset-Hovaere M, Castaing Y et al (2010) Small dead space heat and moisture exchangers do not impede gas exchange during noninvasive ventilation: a comparison with a heated humidifier. Intensive Care Med [Comparative Study Randomized Controlled Trial Research Support, Non-US Gov't] 36(8):1348–1354
28. Conti G, Larrsson A, Nava S, Navalesi P. On the role of non-invasive (NIV) to treat patients during the H1N1 influenza pandemic. http://dev.ersnet.org/uploads/Document/63/WEB_CHEMIN_5410_1258624143.pdf
29. Esquinas A. Humidification practice during H1N1 pandemic. International Survey (unpublished data)
30. Sanner BM, Fluerenbrock N, Kleiber-Imbeck A, Mueller JB, Zidek W (2001) Effect of continuous positive airway pressure therapy on infectious complications in patients with obstructive sleep apnea syndrome. Respiration [Comparative Study] 68(5):483–487
31. Chanques G, Jaber S, Delay JM, Perrigault PF, Lefrant JY, Eledjam JJ (2003) Phoning study about postoperative practice and application of non-invasive ventilation. Ann Fr Anesth Reanim 22(10):879–885
32. Chiumello D, Chierichetti M, Tallarini F, Cozzi P, Cressoni M, Polli F et al (2008) Effect of a heated humidifier during continuous positive airway pressure delivered by a helmet. Crit Care 12(2):R55
33. Duong M, Jayaram L, Camfferman D, Catcheside P, Mykytyn I, McEvoy RD (2005) Use of heated humidification during nasal CPAP titration in obstructive sleep apnoea syndrome. Eur Respir J 26(4):679–685