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<sub>1</sub> 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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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.

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 $\text{FiO}_2$ 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 $\text{FiO}_2$ 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 humidification 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 humidification in NIV, it is usually used without humidification, 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
IPAP can decrease by a value of 0.5–1 cmH\textsubscript{2}O [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
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 identify 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 humidification to NIV therapy and to assess the effect of humidification on adherence to NIV, and its effect on different outcome measures.

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