

Humidification During Invasive and Noninvasive Mechanical Ventilation: 2012

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We searched the MEDLINE, CINAHL, and Cochrane Library databases for articles published between January 1990 and December 2011. The update of this clinical practice guideline is based on 184 clinical trials and systematic reviews, and 10 articles investigating humidification during invasive and noninvasive mechanical ventilation. The following recommendations are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) scoring system: 1. Humidification is recommended on every patient receiving invasive mechanical ventilation. 2. Active humidification is suggested for noninvasive mechanical ventilation, as it may improve adherence and comfort. 3. When providing active humidification to patients who are invasively ventilated, it is suggested that the device provide a humidity level between 33 mg H₂O/L and 44 mg H₂O/L and gas temperature between 34°C and 41°C at the circuit Y-piece, with a relative humidity of 100%. 4. When providing passive humidification to patients undergoing invasive mechanical ventilation, it is suggested that the HME provide a minimum of 30 mg H₂O/L. 5. Passive humidification is not recommended for noninvasive mechanical ventilation. 6. When providing humidification to patients with low tidal volumes, such as when lung-protective ventilation strategies are used, HMEs are not recommended because they contribute additional dead space, which can increase the ventilation requirement and P_aCO₂. 7. It is suggested that HMEs are not used as a prevention strategy for ventilator-associated pneumonia. *Key words:* active humidification, heat and moisture exchanger, heated humidifier, hydrophobic, hygroscopic condenser humidification, passive humidification. [Respir Care 2012;57(5):782–788. © 2012 Daedalus Enterprises]

HMV 1.0 DESCRIPTION

When the upper airway is bypassed during invasive mechanical ventilation, humidification is necessary to prevent hypothermia, disruption of the airway epithelium, bronchospasm, atelectasis, and airway obstruction. In severe

cases, inspissation of airway secretions may cause occlusion of the endotracheal tube.¹ While there is not clear consensus on whether or not additional heat and humidity are always necessary when the upper airway is not bypassed, such as in noninvasive mechanical ventilation (NIV), active humidification is highly suggested to improve comfort.^{2–7}

Two systems, active humidification through a heated humidifier (HH) and passive humidification through a heat and moisture exchanger (HME), are available for warming and humidifying gases delivered to mechanically ventilated patients. There are 3 types of HME or artificial nose: hydrophobic, hygroscopic, and a filtered HME.

Heated humidifiers operate actively to increase the heat and water vapor content of inspired gas.⁸ HMEs operate passively by storing heat and moisture from the patient's exhaled gas and releasing it to the inhaled gas.⁹

The upper airway provides 75% of the heat and moisture supplied to the alveoli. When bypassed, the humidifier needs to supply this missing heat and moisture. Since

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The authors have disclosed a relationship with Teleflex Medical, which manufactures humidification devices.

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the total required moisture input is 44 mg/L, the portion that is supplied by the humidifier is $0.75 \times 44 \text{ mg/L} = 33 \text{ mg/L}$. Under normal respiration, the humidity in the trachea can range from 36 mg/L to 40 mg/L and the optimal required moisture below the carina is 44 mg/L (100% relative humidity [RH] at 37°C). When providing active humidification to patients who are invasively ventilated, it is suggested that the device provide a humidity level between 33 mg H₂O/L and 44 mg H₂O/L and gas temperature between 34°C and 41°C with a RH of 100% to prevent the drying out of secretions in the artificial airway.¹⁰⁻¹⁵ Although modern active humidifiers are capable of delivering gas at temperatures of 41°C at the Y-piece, a maximum delivered gas temperature of 37°C and 100% RH (44 mg H₂O/L) at the circuit Y-piece is recommended.¹⁰⁻¹⁴ According to the International Organization for Standardization (ISO), a sustained delivered gas temperature above 41°C represents a potential thermal hazard to the patient, and the ISO considers using a temperature of 43°C as the extreme over-temperature alarm condition to protect the patient from thermal injury.¹¹ If the inspired gas has a temperature higher than 37°C and is 100% saturated, condensation occurs, causing reduced mucus viscosity and increased pericellular depth fluid. The combination of low-viscosity mucus and excessive pericellular fluid may result in the cilia losing contact with the mucus, which may be too liquid to be properly engaged by the cilia tips. Thus, mucociliary transport velocity may be reduced. Excess condensed water would need to be cleared by the mucosal cells, and the excess heat also may cause cellular damage.^{12,13}

Exposure to humidity levels below 25 mg H₂O/L for 1 hour or 30 mg/L for 24 hours or more have been associated with airway mucosal dysfunction.¹⁶ Therefore, a minimum of 33 mg H₂O/L has been recommended for patients with an artificial airway.¹⁰⁻¹⁴

The performance specifications provided by manufacturers of HMEs are based on in vitro measurements of moisture output, using the ISO 9360 method. However, the in vivo performance of HMEs may differ from manufacturers' specifications.¹⁷ The American National Standards Institute recommends absolute humidity (AH) values of $\geq 30 \text{ mg H}_2\text{O/L}$; the American Association for Respiratory Care (AARC) has recommended AH values of $\geq 30 \text{ mg H}_2\text{O/L}$, while the ISO prefers AH values of $\geq 33 \text{ mg H}_2\text{O/L}$. A HME that delivers 26–29 mg H₂O/L may be adequate for patients without underlying conditions that impair airway clearance^{18,19}; however, HMEs that provide an AH $< 26 \text{ mg/L}$ should not be used. The use of HMEs that deliver an AH of at least 30 mg H₂O/L are recommended, as they are associated with a lower incidence of ETT occlusion.^{17,18}

HMV 2.0 SETTINGS

- 2.1 Critical care
- 2.2 Acute care in-patient
- 2.3 Operating room
- 2.4 Extended care and skilled nursing facility
- 2.5 Home care
- 2.6 Transport

HMV 3.0 INDICATIONS

Humidification of inspired gas during mechanical ventilation is mandatory when an endotracheal or tracheostomy tube is present,^{1,20-24} but optional with NIV.^{20,24}

HMV 4.0 CONTRAINDICATIONS

There are no contraindications to providing physiologic conditioning of inspired gas during mechanical ventilation. An HME is contraindicated under some circumstances.

4.1 Use of an HME is contraindicated for patients with frank bloody or thick, copious secretions.²⁵

4.2 Use of an HME is contraindicated for patients with an expired tidal volume less than 70% of the delivered tidal volume (eg, those with large bronchopleurocutaneous fistulas, tracheal tube cuff malfunction, or presence of uncuffed endotracheal tube).²⁶⁻²⁸

4.3 When providing humidification to patients with low tidal volumes, such as when lung-protective ventilation strategies are used, HMEs are not recommended because they contribute additional dead space, which can increase the ventilation requirement and $P_{a\text{CO}_2}$.²⁵

4.3.1 Artificial airway dead-space reduction allows a significant $P_{a\text{CO}_2}$ reduction that is independent of any respiratory mechanical changes. In patients with ARDS, where low tidal volumes are used, and when managing hypercapnia is warranted, HMEs should be avoided.²⁹

4.3.2 Removal of the HME from the circuit of patients receiving lung-protective strategy significantly reduces dead space and $P_{a\text{CO}_2}$ and increases pH.³⁰

4.3.3 In patients with acute respiratory failure, HMEs substantially increase minute ventilation, ventilatory drive, and work of breathing.³¹

4.4 Use of an HME is contraindicated for patients with body temperatures $< 32^\circ\text{C}$.^{25,28}

4.5 Use of an HME may be contraindicated for patients with high spontaneous minute volumes ($> 10 \text{ L/min}$).^{29,30}

4.6 An HME must be switched to the aerosol bypass mode or removed from the patient circuit during aero-

sol treatments when the nebulizer is placed in the patient circuit.³²⁻³⁵

4.7 The resistance and dead space of the HME may negate the effects of the noninvasive positive pressure and add additional work of breathing.³⁶

4.8 Use of an HME is contraindicated in patients on NIV with large mask leaks, as the patient does not exhale enough tidal volume to replenish heat and moisture to adequately condition the inspired gas.

4.9 Use of an HME increases dead space and P_{aCO_2} and may increase ventilatory requirements for patients who are mechanically ventilated.

HMV 5.0 HAZARDS/COMPLICATIONS

Hazards and complications associated with the use of humidification devices include:

5.1 Potential for electrical shock—HH

5.2 Hypothermia—HME or inadequately set HH; hyperthermia—HH³⁷⁻³⁹

5.3 Thermal injury to the airway from HH; burns to the patient and tubing meltdown if heated-wire circuits are covered or circuits and humidifiers are incompatible

5.4 Underhydration and impaction of mucus secretions (< 26 mg H_2O/L)—HME or HH^{1,11,24,40,41}

5.5 Hypoventilation and/or alveolar gas trapping due to mucus plugging of airways—HME or HH^{1,11,14,24,28,29}

5.6 Possible increased resistive work of breathing due to mucus plugging of airways—HME or HH^{1,7,9,15,39,39}

5.7 Possible increased resistive work of breathing through the humidifier—HME or HH—that could result in elevated airway pressures and possible disconnection⁴²⁻⁴⁴

5.8 Possible hypoventilation due to hypercapnia caused by the increase in dead space—HME⁴¹

5.9 Inadvertent overfilling or pooled condensate resulting in unintentional tracheal lavage—HH^{27,45-57}

5.10 When disconnected from the patient, some ventilators generate a high flow through the patient circuit that may aerosolize contaminated condensate, putting both the patient and clinician at risk for nosocomial infection—HH and HME^{27,43-55}

5.11 Potential for burns to caregivers from heating element—active humidifier

5.12 Patient-ventilator asynchrony and improper ventilator performance due to pooled condensation in the circuit—HH

5.13 Ineffective low-pressure alarm during disconnection, due to resistance through the HME^{40,41}

5.14 Compressible volume loss that can lead to inaccurate effective tidal volume (if not calculated) and reduction on ventilator response—HH and HME⁵⁸

5.15 Dehydration of the airway if temperature is set to body temperature, yet the RH is low—HH¹²

HMV 6.0 LIMITATIONS OF METHODS

6.1 Insufficient heat and humidification can occur with some HME devices, resulting in complications noted in HMV 5.0^{4,10,18,59,60}

6.1.2 A recent evaluation of several HMEs showed that only 37.5% met the AARC and ISO standards (> 30 mg H_2O/L), while 25% performed well under 25 mg H_2O/L . The mean \pm SD difference between measurements obtained in this evaluation and the manufacturer data was 3.0 ± 2.7 mg H_2O/L for devices described as HMEs (maximum 8.9 mg H_2O/L), while the mean difference for 36% of the HMEs was > 4 mg H_2O/L .⁷

6.2 Insufficient heat and humidification can occur with HHs and result in complications noted in HMV 5.0 when:

6.2.1 Temperature settings are improperly selected. Despite the fact that temperature may be a poor indicator of delivered humidity,⁶¹ it remains as the easier parameter to monitor and measure.

6.2.2 Temperature selection is pre-set and non-adjustable rather than based on clinical assessment.¹⁸

6.2.3 Heated wires are inadequately used.

6.2.3.1 Heated-wire circuits are routinely utilized to control condensation/rain-out in the breathing circuit. However, when using a heated-wire circuit, consideration should be given to the fact that heating the gas between the outlet of the humidifier and the Y-piece, in an effort to control condensation, will decrease the RH of the delivered gas. The magnitude of the decrease will be dependent upon the temperature gradient between the humidifier outlet and the patient, and environmental conditions in the immediate patient care area.⁵⁹

6.2.3.2 Decreased RH may result in drying of secretions inside the endotracheal tube, with potential risk of its occlusion.⁶²

6.2.4 Water level in the humidifier falls below manufacturer's suggested level.

6.2.5 The HME selected is not appropriate to the patient's size and tidal volume.

HMV 7.0 ASSESSMENT OF NEED

Humidification is needed by all patients requiring mechanical ventilation via an artificial airway. Conditioning

of inspired gases should be instituted using either an HME or an HH.

7.1 HMEs are better suited for short-term use (≤ 96 h) and during transport.^{9,17,63-66}

7.2 HH should be used for patients who exhibit contraindications for HME use.^{9,17,56}

In addition, recent meta-analyses comparing HHs and HMEs revealed the following conclusions:

7.3 There is little evidence of an overall difference between HMEs and HHs in preventing mortality and other complications in patients who are mechanically ventilated.⁶⁷

7.4 There is no significant difference in the incidence of ventilator-associated pneumonia in patients humidified with HMEs versus HHs.⁶⁸⁻⁷²

7.5 Further research is needed relating to hydrophobic versus hygroscopic HMEs and the use of HMEs in the pediatric and neonatal populations.

HMV 8.0 ASSESSMENT OF OUTCOME

Humidification is assumed to be appropriate if, on regular careful inspection, the patient exhibits none of the hazards or complications listed in HMV 5.0.

The presence of condensate in the ET connector implies that RH is 100%, as demonstrated by Ricard et al.⁷³

HMV 9.0 RESOURCES

9.1 Equipment. Appropriate equipment should be available to provide for adequate humidification of the inspired gas. Such equipment may include but is not limited to:

9.1.1 Humidification device

9.1.2 A system to monitor inspired gas temperature and to alarm when the temperature falls outside a preset range (for HH)

9.1.3 Sterile water for HH

9.1.4 Equipment necessary to adhere to universal precautions.

9.2 Humidifier performance specifications should be checked to assure adequate heating and humidification during expected peak inspiratory flow rate and minute ventilation delivered by the mechanical ventilator. HHs selected for use should meet the specifications of the ISO.¹¹

9.3 Personnel. Licensed or credentialed respiratory therapists or individuals with similar credentials (eg, MD, RN) who have the necessary training and demonstrated skills to correctly evaluate humidification during mechanical ventilation, assess the patient and the patient-ventilator system, and the ability to exercise appropriate clinical judgment.

HMV 10.0 MONITORING

While the presence of condensate has been considered an indication of adequate performance of the humidifier, it is not a reliable clinical marker for adequate humidification when ambient air temperature is high.¹⁵

The humidification device should be routinely inspected during the patient-ventilator system check, and condensate should be removed from the patient circuit as necessary. Passive humidification devices should be inspected and replaced if secretions have contaminated the insert or filter, and/or if flow resistance has increased, causing an unacceptable increase in the work of breathing. The following variables should be recorded during equipment inspection:

10.1 Humidifier setting (temperature setting or numeric dial setting or both). During routine use on an intubated patient, a HH should be set to deliver an inspired gas temperature of $\geq 34^{\circ}\text{C}$,⁸ but $< 41^{\circ}\text{C}$ at the circuit Y-piece^{7,9} and should provide a minimum of 33 mg/L of water vapor.¹¹ The ISO considers that an inaccuracy of $< 2^{\circ}\text{C}$ of the displayed measured gas temperature does not compromise the clinical condition or the safety of the patient.¹¹

10.1.1 NIV. Gas temperatures during NIV should be selected based on patient comfort/tolerance/adherence and underlying pulmonary condition.⁷

10.2 Inspired gas temperature. While temperatures could be measured at the outlet port of the HH, it should always be measured near the patient's airway.^{6,29} The ISO recommends that the measured gas temperature should be always within $\pm 2^{\circ}\text{C}$ of the arithmetic mean of the 2 standard temperature sensors in a steady-state condition for the maximum set temperature.¹¹

10.2.1 The inspiratory gas should not exceed 41°C at the circuit Y-piece, with an over-temperature limit at 43°C , at which point the heater should shut down.¹¹

10.2.2 When a heated-wire patient circuit is used (to prevent condensation) on an infant, the temperature probe should be located outside of the incubator or away from the direct heat of the radiant warmer.

10.3 Alarm settings (if applicable). High temperature alarm should be set no higher than 41°C (with a 43°C over-temperature limit) and the low temperature alarm should be set no lower than 2°C below the desired temperature at the circuit Y-piece.

10.4 Water level and function of automatic feed system (if applicable).

10.5 Quantity and consistency of secretions. Characteristics should be noted and recorded. When using an HME, if secretions become copious or appear increas-

ingly tenacious, an HH should replace the HME. If an HH is being used, the temperature at the patient Y-piece should be increased to deliver more AH, and the wire temperature should be adjusted to allow for optimal RH.

10.6 Airway obstruction. The presence of copious secretions increases the resistance of air flow through the HME. This event may increase peak pressures and induce changes of the flow waveforms consistent with those observed with airway obstruction. If these changes persist after changing the HME due to copious secretions, an HH should be used instead.

HMV 11.0 FREQUENCY

All patients with an artificial airway requiring mechanical ventilation should receive continuous humidification of inspired gases.

HMV 12.0 INFECTION CONTROL

12.1 Reusable HHs should be subjected to high-level disinfection between patients. Clean technique should be observed when manually filling the water reservoir. Sterile water should be used.

12.2 When using a closed, automatic feed system, the unused portion of water in the water feed reservoir remains sterile and need not be discarded when the patient circuit is changed. However, the water feed system should be designated for single patient use only.

12.3 Condensation from the patient circuit should be considered infectious waste and disposed of according to hospital policy, using strict universal precautions.

12.4 Because condensate is infectious waste, it should never be drained back into the humidifier reservoir.

12.5 Circuits should be changed as needed due to lack of functionality or when visibly soiled, unless otherwise specified by the manufacturer.

12.6 Passive humidifiers do not need to be changed daily for reasons of infection control or technical performance. They can be safely used for at least 48 hours, and with some patient populations some devices may be able to be used for up to 1 week.³⁸

HMV 14.0 RECOMMENDATIONS

The following recommendations are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE)⁷⁴ criteria.

14.1 Humidification is recommended on every patient receiving invasive mechanical ventilation. (1A)

14.2 Active humidification is suggested for NIV, as it may improve adherence and comfort. (2B)

14.3 When providing active humidification to patients who are invasively ventilated, it is suggested that the device provide a humidity level between 33 mg H₂O/L and 44 mg H₂O/L and gas temperature between 34°C and 41°C at the circuit Y-piece, with an RH of 100%. (2B)

14.4 When providing passive humidification to patients undergoing invasive mechanical ventilation, it is suggested that the HME provide a minimum of 30 mg H₂O/L. (2B)

14.5 Passive humidification is not recommended for NIV. (2C)

14.6 When providing humidification to patients with low tidal volumes, such as when lung-protective ventilation strategies are used, HMEs are not recommended because they contribute additional dead space, which can increase the ventilation requirement and P_aCO₂. (2B)

14.7 It is suggested that HMEs are not used as a prevention strategy for ventilator-associated pneumonia. (2B)

HMV15.0 IDENTIFYING INFORMATION AND AVAILABILITY

15.1 Adaptation

Original Publication: *Respir Care* 1992(8);37:887–890.

15.2 Guideline Developers

American Association for Respiratory Care Clinical Practice Guidelines Steering Committee

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15.3 Source(s) of Funding

None

15.4 Financial Disclosures/Conflicts of Interest

Mr Walsh and Dr Restrepo have disclosed a relationship with Teleflex Medical, which manufactures humidification devices.

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