Humidification of inspired gases in the mechanically ventilated patient

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Points to ponder:

- Basic concepts
- Physiology and Thermodynamic basics of Humidification
- Requirements for humidification devices
- Devices for non-intubated vs. intubated patients
- Over vs. under humidification
- Heated Humidification vs. Heat and Moisture exchangers (artificial nose)
- Special considerations during humidification
- Humidification and VAP
Basic concepts:

- Humidification of inspiratory gases required if upper airway is bypassed
- Prevention of hypothermia, insissipation of airway secretions, destruction of airway epithelium and atelectasis
- Devices should deliver a minimum of 30 mg H2O / l of delivered gas @ 30 °C
- HH : actively increases heat and vapour content of the inspiratory gas
- HME: operates passively ; stores heat and moisture form the patients exhaled gas releasing it to the inhaled gas
Which clinical settings?

- Critical care
- Acute care of inpatients
- Extended care and experienced nursing care facilities
- Home care
- Prolonged transport
Indications:

- Humidification of inspiratory gas is mandatory if endotracheal tube or tracheostomy is present
Contraindications:

- Extremely thick copious and bloody secretions
- HME CI if patient’s expiratory tidal volume is < 70 % of delivered tidal volume (e.g. large bronchopleurocutaneous fistulas, incompetent / absent Et tube cuffs)
- Hypothermic patients with temp < 32°C
- High spontaneous minute volume > 10 l/min
Potential hazards and complications:

- Electric shock (HH)
- Hypothermia (HME/HH)
- Hyperthermia (HH) & overhumidification - thermal injury to the airway
- Under hydration and impaction of mucous secretions (HME/HH)
- Hypoventilation / alveolar gas trapping / mucous plugging of airways (HME/HH)
- Increased resistive work of breathing (HME/HH)
- Possible hypoventilation due to increased dead space ventilation (HME)
- Overfilling of reservoir – tracheal lavage (HH)
- Increased risk for nosocomial infection with aerolization of contaminated condensate / tracheal lavage from pooled condensate in circuit
- Pooled condensate – increased airway pressures
- Ineffective low-pressure alarm during disconnection 2º to increased resistance through HME
Key points:

- Insufficient heat and humidification result from improper temp settings, if H2O level falls below the manufacturer’s suggested level.
- HME: short term use < 96 hrs, transport.
- HH: > 96 hrs, CI for HME use.
- Monitoring include daily Pt- ventilator circuit checks.
- Removal of condensate from tubing as necessary.
- Replace HME if secretions have contaminated the files.
- Check humidifier settings: insp temp 33 °C.
  : minimum 30 mg / l of water vapour.
- Inspiratory gas temp should not exceed 37°C: HAL : 37°C, LAL : 30°C.
Physiology and thermodynamics:

- **Absolute Humidity (AH):** the total mass of water vapour in a given volume of gas at a given temperature ($\text{g/m}^3$)
- **Relative humidity (RH):** the actual mass of water vapour as a percentage of the mass of saturated water vapour.
Fig. 1. Water content and temperature of the inspiratory and expiratory air during nasal respiration of room air. The circled values indicate the effective water losses that are due to evaporation from the corresponding regions of the respiratory tract. (*Data from Refs. [1–3].*)
Clearance of surface liquids and particles in the lung depend on the beating cilia, airway mucus, and transepithelial water flux.

Cilia function and mucous composition influenced by temp and humidification

Heating and humidification progressive downwards with isothermic saturation boundary (100% RH at 37°C or AH of 43 g/m³) just below the carina

250ml water and 350 kcal of energy lost from respiratory tract / day

10-25% returned to mucosa during expiration due to condensation

During intubation – nasotracheal system bypassed with the ISB moving towards the periphery.
Fig. 2. Water content in the inspiratory and expiratory air in intubated, ventilated patients without conditioning of the respiratory gases. The circled value corresponds to the effective water loss due to evaporation from the lower respiratory tract (absolute humidity in mg/L). (Data from Refs. [1–3,5,8].)
Physiology (cont):

- Mucus flow is markedly reduced when the RH at 37° C falls below 75% (AH 32 g/m³) and ceases when the RH is 50% (AH of 22 g/m³).
- Mucociliary function is also impaired by URTI conditions, dehydration, anesthetic agents, opioids, atropine.
- High FiO₂ also depresses tracheal mucous velocity within hours.
Requirements for devices:

- **Ideal humidification:**
  - The inspired gas is delivered into the trachea at 32-36 °C with a water content of 30-43 g /m³.

- The set temp remains constant and does not fluctuate.

- Humidification and temp remain unaffected by high gas flow and can be provided for air, oxygen, inspired gas or anesthetic agents.

- Humidifier can be used with spontaneous or controlled ventilation.

- Safety measures are in place e.g. alarms @ overheating, overhydration.

- Resistance, dead space and compliance characteristics do not adversely affect spontaneous breathing modes.

- Sterility of respired gas is not compromised.
Different devices:

- **Water Bath Humidifiers:**
  - Cold water humidifiers – not in common use
  - Hot water humidifiers “gold standard”:
    - Hot water “blow – by” humidifier (Fisher-Paykel™ humidifier)
    - Hot water “bubble” humidifier

- **Heat and moisture exchangers:**
  - Hydrophobic or hydroscopic, HMEF
  - Modern HMEs are light with small dead space
  - Hygroscopic absorb moisture (paper-like material is chemically coated with calcium/lithium chloride)
  - Average use: 4 days
Fig. 4. Water content of the inspiratory and expiratory air in intubated, ventilated patients when an HME of intermediate efficiency is used. The circled value corresponds to the effective water loss from the lower respiratory tract and can be measured at the respirator’s exhaust outlet (minus 1 mg/L due to humidity in the gas supply) (absolute humidity in mg/L). (Data from Refs. [8,15,17].)
Over and underhumidification:

- **Underhumidification:**
  - In adults dry gas ventilation induced increase in daily $H_2O$ deficit reaches 100-200g of water
  - Increased caloric deficit can reach 60-120 kcal/ day
  - Hypothermia is a potential complication of dry gas ventilation is combined with e.g. prologed ventilation, low ambient room temp, massive transfusion, CVVH
Box 1. Consequences of ventilation without conditioning of inspired medical gases [2,71]

_Cyto-morphologic airway modifications_
Decrease in sol phase depth
Hyperviscosity of airway secretions
Tracheal inflammation
Deciliation, epithelial ulceration, and then necrosis

_Functional airway modifications_
Decrease in the humidification capabilities
Downward shift of the ISB
Decrease in mucus transport velocity, secretions retention
Decrease in the bronchospasm threshold
Alteration of the ciliary function, ciliary paralysis
Airway obstruction and increase in airflow resistance

_Pulmonary, mechanical, and functional alterations_
Atelectasis
Decrease in functional reserve capacity and compliance
V/Q mismatching, increase in intrapulmonary shunt, hypoxemia
Pulmonary infection
Overhumidification:

- Aerosol droplets can lead to the following parenchymal changes:
- Neutrophilic infiltrates of the lungs and bronchioles
- Interstitial and alveolar oedema
- Atelectasis
- Lung consolidation / bronchopneumonia
- Decreased lung compliance
- Increase in intrapulmonary shunts
- Increase in airway resistance
- Mist therapy can lead to a drowning effect with risk of local and systemic inflammation
Special considerations:

- ARDS
- Humidification during weaning
- Non-invasive ventilation
- Resistance to gas flow of HME
- Heat humidification in patients with Hypothermia
Fig. 2. Algorithm used by author’s group for choosing humidification devices in the adult ICU. Check for condensate between the HME and tracheal tube. If condensate is present, relative humidity is greater than 100%. The use of HMEs should be avoided when large volumes of secretions may occlude the media (e.g., in patients who have pulmonary edema or mucopurulent pneumonia. The term “bloody secretions” included patients who have hemoptysis (secretions appear to be blood). Small streaks of blood are permissible. Tenacious sputum is related to two consecutive suctioning procedures in which sputum is considered thick (i.e., secretions remain stuck to the walls of the suction catheter after it is rinsed with saline). This judgment is made without regard to amount; a small amount of thick sputum warrants a change to heated humidification. (This exclusion of HMEs concerns inadequate humidification in the case of thickened secretions, not concerns of filter occlusion.) Low-tidal-volume strategy includes the use of permissive hypercapnia and tidal volume ($V_T$) of 6 mL/kg or less. Removal of the HME in these cases can improve CO₂ elimination and reduce the minute ventilation requirement.
ARDS:

- Clinicians should be cognizant of the relationship between the internal volume of the HME and set tidal volume during ventilation.
- Added dead space is created when a flex tube and closed circuit suction device is added.
  - HME: 60 ml
  - Connecting tube: 20 ml
  - Closed suction circuit: 7 ml
- Increased risk of PaCO$_2$ increase in ARDS, if elevated change to HH (mean decrease of 17 mmHg).
- If low tidal volume ventilation is used: ARDS and hypercapnoea, HH is the choice.
Weaning:

- 50-100ml added dead space from HME can be problematic if weaning attempted in patients with poor pulmonary mechanics and muscle weakness.
- Increase in dead space can lead to an increase in WOB.
- Dead space can be overcome by graded increase in PS but:
- HH is choice if: ARF, Mech vent > 7 days, weaning includes SBT.
Non-invasive ventilation:

- High gas flow quickly results in dryness, mucosal cracking and bleeding
- HH is choice with RH 100% and temp 30°C
- No HME:
  - Increase in dead space, increase in \( \text{paCO}_2 \)
  - Increased WOB, RR and MV
Resistance to gas flow of HME:

- Resistance lower than in tracheal tube
- Daily inspection for blood and secretions
- Transparent cover imperative to visualize filter paper
- Removal if significant secretions present
Humidification and VAP:

- Inhalation therapy and the risk of VAP
- Breathing system contamination and the risk of VAP
- Preventing colonization of the breathing system
The Effect of Humidification on the Incidence of Ventilator-associated Pneumonia

Jean-Damien Ricard, MD, PhD\textsuperscript{a,c,*}, Alexandre Boyer, MD\textsuperscript{b}, Didier Dreyfuss, MD\textsuperscript{a,c}
Inhalation therapy:

- HH: Small particles are ideal vectors for transmission of bacteria, delivered straight to respiratory tract
- Theoretical increased risk for VAP
- Stems from 1967, 5 fatal cases of Klebs pneumonia in patients that received nebulized bronchodilators
Breathing system contamination:

- Contamination risk:
  - 33% @ 2 hrs
  - 64% @ 12 Hrs
  - 80 % @ 24 Hrs
- Increased condensate, increased colonization
- Tubing closest to patient most densely populated
- Previous common practice to replace tubing every 24 hrs
- Now: no routine change unless system clearly contaminated or mechanically malfunctioning
Preventing colonization:

- HME: 11%
- HH: 54%
- HH vs. HME: no difference in incidence of VAP although theoretical advantage in favour of HME
<table>
<thead>
<tr>
<th>Study</th>
<th>Number of patients</th>
<th>Incidence of ventilator-assisted pneumonia</th>
<th>Relative risk with HMEs (95% confidence interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heated humidifier</td>
<td>HME (%) (# patients)</td>
<td></td>
</tr>
<tr>
<td>Martin et al [25]</td>
<td>42</td>
<td>19 (8)</td>
<td>0.34 (0.08–1.49)</td>
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<tr>
<td>Roustan et al [29]</td>
<td>61</td>
<td>14.7 (9)</td>
<td>0.66 (0.24–1.86)</td>
</tr>
<tr>
<td>Branson et al [26]</td>
<td>32</td>
<td>9 (3)</td>
<td>1.65 (0.42–6.51)</td>
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<tr>
<td>Dreyfuss et al [27]</td>
<td>70</td>
<td>11.4 (8)</td>
<td>0.86 (0.32–2.34)</td>
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<tr>
<td>Branson et al [30]</td>
<td>49</td>
<td>5.5 (3)</td>
<td>1.1 (0.23–5.21)</td>
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<tr>
<td>Boots et al [28]</td>
<td>41</td>
<td>17 (7)</td>
<td>1.09 (0.48–2.49)</td>
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<tr>
<td>Kirton et al [31]</td>
<td>140</td>
<td>15.7 (22)</td>
<td>0.36 (0.17–0.79)</td>
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<tr>
<td>Kollef et al [32]</td>
<td>147</td>
<td>10.2 (15)</td>
<td>0.90 (0.46–1.78)</td>
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<td>Memish et al [33]</td>
<td>120</td>
<td>15.8 (19)</td>
<td>0.72 (0.38–1.37)</td>
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<tr>
<td>Lacherade et al [34]</td>
<td>184</td>
<td>28.8 (53)</td>
<td>0.88 (0.63–1.23)</td>
</tr>
</tbody>
</table>

Abbreviation: HME, heat and moisture exchanger.
Cochrane results:

Main results

We included 33 trials with 2833 participants, 25 studies were parallel group design (n = 2710) and eight crossover design (n = 123). Only three included studies reported data for infants or children. There was no overall effect on artificial airway occlusion, mortality, pneumonia, or respiratory complications; however, the PaCO$_2$ and minute ventilation were increased when HMEs were compared to HHs and body temperature was lower. The cost of HMEs was lower in all studies that reported this outcome. There was some evidence that hydrophobic HMEs may reduce the risk of pneumonia and that blockages of artificial airways may be increased with the use of HMEs in certain subgroups of patients.
Devices Used to Humidify Respired Gases
Jörg Rathgeber, Dr.
Consequences of Under- and Over-humidification

Thierry M. Sottiaux, MD
Humidification of Respired Gases During Mechanical Ventilation: Mechanical Considerations

Richard D. Branson, MS, RRT
The Effect of Humidification on the Incidence of Ventilator-associated Pneumonia

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