Heated Humidification

Clinical Evidence Summary

Fisher & Paykel HEALTHCARE

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Reviews. From principles to application

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INTRODUCTION

The three main functions of the upper airway are to filter, warm and humidify inspired gases.[1] Virtually all particulate matter is removed, while inspired gases are warmed to body temperature (37 °C) and saturated to 100% relative humidity (44 mg H_2O/L).[1] This section reviews the principles of airway physiology and defense, to develop an understanding of factors that must be considered in patients receiving respiratory support.

AIRWAY DEFENSES

The primary mechanical defense mechanisms of the upper airway are sneezing, coughing, gagging and filtration via nasal mucosa. A second line of defense is provided by the mucociliary transport system, an extracellular physical barrier that traps and neutralizes pathogens and contaminants and transports them out of the airway.[2] This system is the only remaining mechanical airway defense in patients with bypassed airways and relies on the heat and humidity of inspired gas for optimal function.

The mucociliary transport system is composed of three layers:[2]

1. A cellular layer – including secretory, absorptive, sensory and ciliated cells.
2. An aqueous layer (periciliary fluid) – containing a thin 5–6 µm continuous sheet of low-viscosity fluid.
3. A viscoelastic gel layer (mucus) – comprising mucus that is secreted in response to contaminants or irritants. The mucus is made up of 95% water and 5% glycoproteins, proteoglycans and lipids in a colloidal state.

Cilia on the surface of ciliated cells beat in frequency and coordination with the cilia of neighboring cells and are bathed in periciliary fluid.[2] In response to stimulation, water is absorbed from the periciliary fluid to form mucus, which is drawn towards the larynx by the beating of cilia.[2] The function of the mucociliary transport system is dependent on coordination between the cellular, aqueous and viscoelastic layers of the airway mucosa, and is altered by changes in cilia beat frequency, periciliary fluid rheology and depth, and mucus rheology.[2]

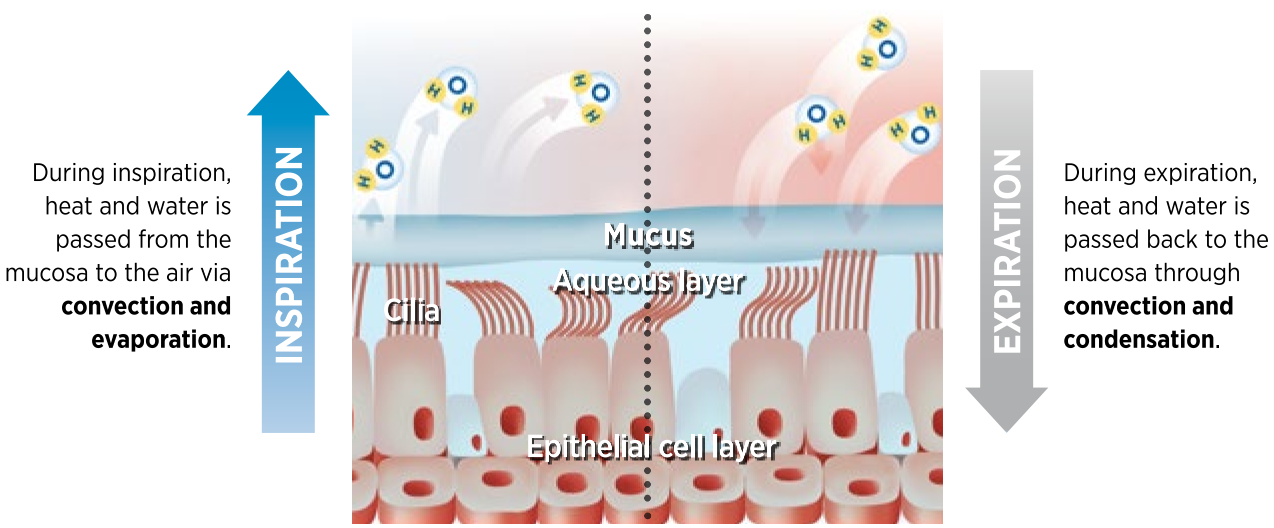


Figure 1: The mucociliary transport system protects the airway from debris, while facilitating heating and humidification of inspired gas.

GAS CONDITIONING

The temperature and humidity of inspired gas are crucial for optimal functioning of the mucociliary transport system, as the delivery of suboptimal heat and moisture causes a progressive slowing of the system and an inefficient airway defense.[2]

During each breath, the respiratory tract adds heat and moisture to gases during inspiration and recovers a fraction of this heat and moisture upon expiration. Air from the environment is conditioned so that the gas reaches the alveoli at core temperature and is fully saturated with water vapor (44 mg H_2O/L at 37 °C, in a normothermic patient). This state is sometimes referred to as body temperature and pressure, saturated (BTPS). The point in the respiratory system at which inspired air reaches this level of heat and humidity is called the isothermic saturation boundary (ISB). It is located around the level of the main stem bronchi in an adult during normal quiet breathing of room air, but it's position can vary with the heat and moisture content of inspired air and breathing patterns.[3]

Consequently, a temperature and humidity gradient exist along the airway, from the ambient temperature and humidity at the airway opening to the core temperature and 100% relative humidity at the ISB. The mucosa above the ISB, which provides heat and moisture during inspiration, is incompletely warmed and moistened from the systemic reserve before expiration starts. Expired alveolar gas will therefore encounter a cool mucosa, which induces condensation and releases moisture and energy back to the mucosa (Figure 1). As a result, there is a direct and dynamic relationship between expired and inspired humidity.[2,3]

MAINTAINING BALANCE DURING RESPIRATORY SUPPORT

Many aspects of airway physiology are bypassed or eliminated during invasive ventilation or are compromised with noninvasive ventilation strategies. In particular, when a patient breathes through an endotracheal or tracheostomy tube, the upper airway is bypassed, and gas is delivered directly to the lower airway with minimal opportunity for normal conditioning.

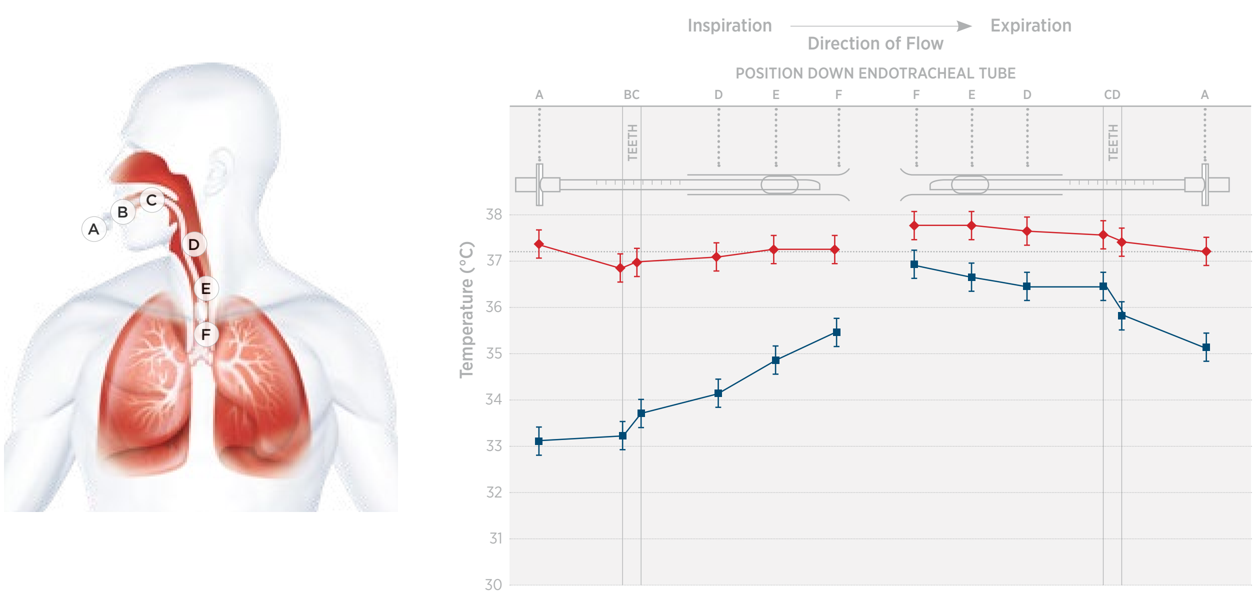


Figure 2: Changes in temperature along the intubated airway of an invasively ventilated patient during inspiration and expiration. The red line and diamonds represent the temperature profile when the inspired gas temperature was set to 37 °C. The blue line and squares represent the profile when the inspired gas temperature was set to 30 °C. Image adapted from Ryan et al. (2002).[4].

Airway workload and water loss are neutral only when the inspired gas is delivered at body temperature and saturated. As the mucosa of an intubated patient has limited ability to warm inspired air through the tube and cannot increase water content (Figure 2), inspired air at a temperature lower than body temperature or not fully saturated with water vapor increases the workload for the lower respiratory tract. When mechanical ventilation lasts for more than a few hours, gases used for respiratory support should be delivered to the airway at body temperature and saturated to minimize the workload on the lower respiratory tract for optimal airway function.[4]

KEY POINTS

- The mucociliary transport system is important for both conditioning inspired air with heat and moisture and preventing pathogens from reaching the lungs.
- Gas is conditioned for respiration from the point of inspiration to the ISB by numerous mechanisms.
- When the upper airways are bypassed, gases should be conditioned prior to inspiration to minimize the workload of the lower respiratory tract.

INTRODUCTION

This review provides an overview of the key concepts of humidity and thermoregulation, with an aim to facilitate understanding of the role that heat and humidity play in achieving optimal airway health and function during invasive ventilation.

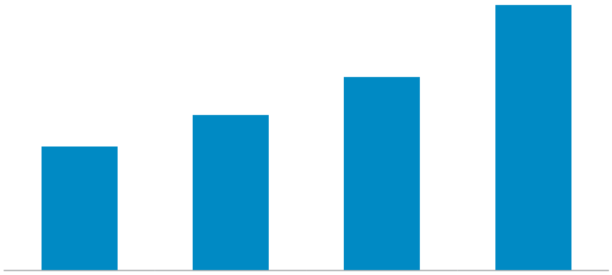
WHAT IS HUMIDITY?

Humidity refers to the presence of water vapor in the atmosphere or a gas and can vary with temperature. The presence of water vapor may be expressed in two ways:[3]

- Absolute humidity (AH) refers to the mass of water vapor held by a volume of gas irrespective of temperature and is expressed as milligrams of water per liter of gas (mg H_2O/L).
- Relative humidity (RH) refers to the mass of water vapor held by a volume of gas relative to the maximum mass of water that the volume of gas could hold at a given temperature and is expressed as a percentage.

WATER VAPOUR ITSELF REFERS TO MOLECULES OF WATER IN THE GASEOUS STATE, WHICH ARE INVISIBLE TO THE EYE.

There is a fixed relationship between absolute humidity, relative humidity and temperature. Gas is described as saturated, i.e. at 100% RH, when it is holding water vapor at its maximum capacity for the given temperature. However, when saturated gas is heated, its capacity to hold water increases. So, although the absolute water content is unchanged, the increase in capacity means the relative humidity of the gas decreases (< 100% RH). Conversely, when saturated gas is cooled, its capacity to hold water vapor decreases and the excess water vapor which now cannot be stored is lost as condensation. The gas then reaches a new equilibrium of saturation at the lower temperature.[2]



Temperature	23 °C	27 °C	31 °C	37 °C
Absolute humidity (AH)	21 mg/L	26 mg/L	32 mg/L	44 mg/L
Relative humidity (RH)	100%	100%	100%	100%
				OPTIMAL HUMIDITY

Figure 3: The capacity of gas to hold water vapor increases with temperature. When gas is heated, the maximum water content it can hold increases. All of these samples are saturated (100% RH), but hold different absolute levels of water vapor.

The total energy of air is composed of sensible heat (reflected in the air temperature) and latent heat (reflected in the water vapor mass). Altering the temperature of water requires approximately twice the energy as changing the temperature of gas. Changing gas temperature without an alteration of the water vapor content has only a small effect on the total energy of the gas compared to the uptake of energy from adding water vapor. Consequently, humidified air contains more energy than dry air at the same temperature.

WHAT IS OPTIMAL HUMIDITY?

In the context of the intubated patient, Optimal Humidity refers to the delivery of inspired gas at body temperature and saturated (37 °C, 100% RH), therefore making it thermodynamically neutral.[4] Airway workload and airway water loss increase linearly as the inspired gas decreases from these optimal levels, as does the occurrence of mucociliary dysfunction.[2]

It has been proven that the temperature and humidity of inspired gas are crucial determinants of mucosal function. Only inspired gas that is conditioned to core temperature and with 100% saturation allows optimal mucociliary transport velocity (Figure 4).

Figure 4 is a graphic representation of mucosal function vs. inspired humidity. It shows a continuum of mucosal dysfunction with any deviation from Optimal Humidity. The degree to which deviation from Optimal Humidity impacts mucosal function depends on the magnitude of the deviation from optimal, the duration of the deviation, and patient health.

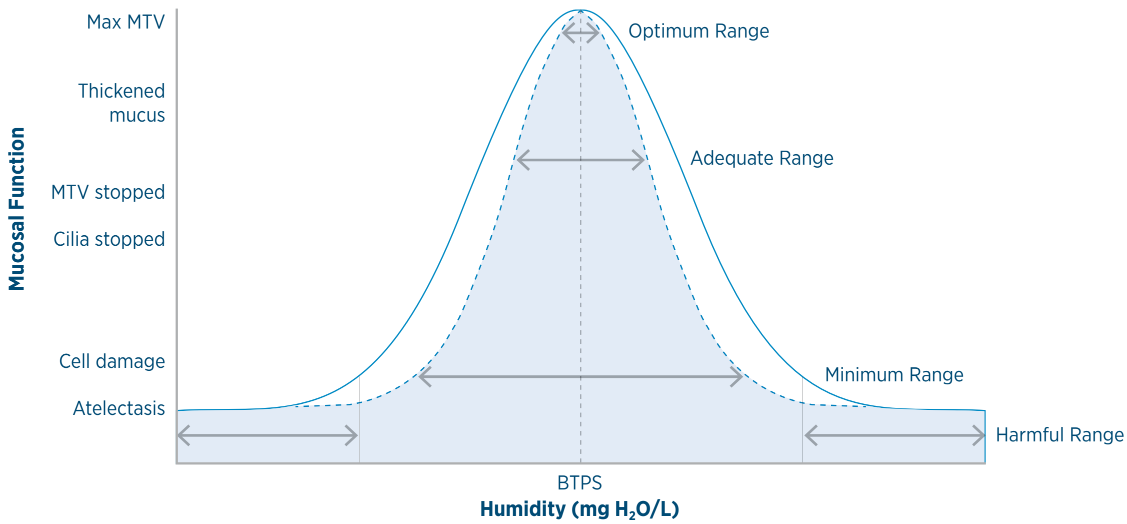


Figure 4: Mucosal function vs. inspired humidity curve. Image adapted from Williams et al. (1996).[2]
Abbreviations: BTPS, body temperature and pressure, saturated with water vapor; MTV, mucociliary transport velocity.

The curve is unique for each individual patient context and therapy factors; however, the parabolic shape of the curve should be similar between individuals.[2] The curve is expected to narrow with poor health, as it assumes that the critically ill patient has other systemic demands that make them less tolerant to water mass and thermal challenges to their airway mucosa. This may include when the patient is intubated, when gas is delivered at high flow rates, or when therapy continues over a prolonged period. This variation means that humidification requirements may differ between patients or could change for a single patient over time.[5]

KEY POINTS

- There is a fixed relationship between absolute humidity, relative humidity, and temperature.
- The degree to which deviation from Optimal Humidity impacts mucosal function depends on the extent and duration of the deviation, as well as on patient health.

INTRODUCTION

There is a strong rationale for delivering inspiratory gas to intubated patients as close to Optimal Humidity as possible. This review outlines and compares the methods available for heating and humidifying respiratory gases and their applicability to patient and therapy requirements.

Medical gases and room air are often much drier than our lungs need, forcing the respiratory system to compensate (Table 1).[6]

Table 1: Mean temperature and relative humidity (RH) measurements for piped medical gases and ambient room air at Royal Women's Hospital (Melbourne, Australia) compared to optimal humidity for respiratory function. Data from Dawson et al. (2014).[6]

Medical oxygen (at the wall outlet)	Room air	Optimal humidity
23 °C	23 °C	37 °C
2.1% RH	41.1% RH	100% RH
0.4 mg H_2O/L	8.4 mg H_2O/L	44 mg H_2O/L

Humidification of respiratory gases prior to airway delivery is commonly achieved by either active humidification using a heated humidifier or passive humidification using a heat-and-moisture exchanger (HME). Both act to warm gas and add humidity, thereby adding energy.[3,5] The degree to which they do this, and the circumstances in which they are appropriate, varies based on the type of device.

KEY FEATURES OF ACTIVE VERSUS PASSIVE HUMIDIFIERS

Active humidifiers enable air to be transported over a heated water reservoir. The water within the chamber evaporates, adding water vapor into the gas path. Water vapor cannot transmit an infection,[3] as water molecules are many times smaller than bacteria and viruses. The HH is placed in the inspiratory limb of the ventilator circuit, close to the ventilator. After gas passes through the reservoir and gains humidity, the gas travels along the inspiratory limb to the patient's airway (Figure 5).[3,5]

Passive HMEs (also called artificial noses) mimic the humidifying action of the nasal cavity. HMEs are placed between the Y-piece and the patient's airway.[3] These devices contain a condenser element that retains moisture on expiration so that when the next inspired breath passes through it may passively gain heat and humidity. Unlike when using an HH, this means the conditioning ability of an HME relies on the provision of heat and moisture by the patient.[5] There is considerable heterogeneity in the humidification performance of HMEs, with absolute humidity values amongst 48 tested devices ranging from 17 to 32 mg H_2O/L.[7]

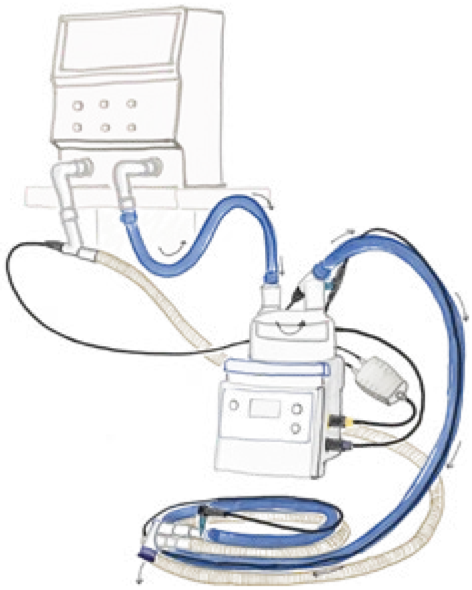


Figure 5: Active humidifiers add heat and humidification to medical gases prior to inspiration. Arrows indicate the flow of gas to the patient for inspiration through the inspiratory limb (blue).

RECOMMENDATIONS AND CONTRAINDICATIONS

There are no contraindications to the principle of adding heat and humidity to inspired gases, or to using a heated humidifier to do this. However, there are some instances in which HMEs are contraindicated (Table 2).

Table 2 summarizes recommendations by the American Association for Respiratory Care (AARC) for humidification during invasive and noninvasive respiratory support across all populations.[8] The AARC recommends the use of an HH over an HME for noninvasive ventilation based on data indicating improved patient comfort and tolerance.

Table 2: American Association for Respiratory Care recommendations for humidification during invasive and noninvasive respiratory support.[8]

Humidification is recommended for **all** patients undergoing invasive ventilation.	When providing HME to patients undergoing invasive ventilation, it is suggested that a **minimum** humidity level of 30 mg H_2O/L is used.
HH devices are recommended for **noninvasive respiratory support**, as they may improve patient adherence and comfort.	HMEs are **not recommended** for noninvasive ventilation.
It is suggested that the HH device achieves a humidity level between 33–44 mg H_2O/L and 34–41 °C at the circuit Y-piece, and relative humidity of 100%.	HMEs are **not recommended** in patients with low tidal volumes (such as when lung-protective ventilation strategies are used) due to the **addition of dead space**.
Due to the features and mechanisms by which HMEs operate, they are **contraindicated** in some patient groups, including those with frank bloody or thick, copious secretions, an expired tidal volume < 70% of delivered tidal volume, a body temperature < 32 °C, and those on noninvasive ventilation with large mask leaks.	

In addition to the absolute contraindications for HMEs specified by the AARC in patients receiving ventilatory support, there are many other contexts in which significant concerns around the use of HMEs have been raised in the literature.

KEY POINTS

- The addition of heat and humidification to gases delivered during respiratory support is beneficial for patients, regardless of the delivery method. However, the benefit of adding heat and moisture is maximized when inspired air is closest to normal physiological conditions.
- There are currently no published contraindications for heating and humidifying respiratory gases or achieving this with a heated humidifier. There are many contexts where use of an HME is contraindicated.

INTRODUCTION

While heated humidifiers are placed in the inspiratory limb of the circuit, close to the ventilator, HME devices are placed between the Y-piece and the patient, close to the airway.[5] The positioning of HME devices may increase resistance to air flow not only during inspiration but also during the expiratory phase.[5] This review highlights the differences between HH and HME devices for both ventilator mechanics and lung mechanics, with a focus on patient impacts.

EFFECTS ON THE VENTILATOR

The use of active HH devices in patients undergoing volume-controlled mechanical ventilation permits the use of lower tidal volumes at isocapnic conditions compared with HMEs, leading to a reduction in plateau airway pressure and driving pressure.[9,10] In a crossover study of 18 brain-injured patients with acute respiratory distress syndrome (ARDS), replacing the HME with an HH allowed
a median reduction in the tidal volume of 120 mL (P < 0.001, 95% CI [98, 144]), while plateau airway pressure and driving pressure were both reduced by 3.7 cmH_2O (P < 0.001, 95% CI [-29, -4.3]).[10] Reduction in tidal volume and driving pressure are among the most important modifiable factors capable of improving survival in patients with ARDS.[10] Importantly for patients with brain injury, this approach is not associated with alveolar derecruitment, hypoxemia, changes in cerebral perfusion or altered blood flow.[10]

Switching an HME for an HH enables:

↓ TIDAL VOLUME

↓ PLATEAU AIRWAY PRESSURE

↓ DRIVING PRESSURE

Pitoni et al., 2020

In patients receiving pressure-support ventilation, the use of an HH can reduce pressure support requirements compared with HME, which may be of assistance when weaning from mechanical ventilation.[11,12] A randomized, crossover study of 11 patients with chronic respiratory failure found that an increase in pressure-support ventilation of ≥ 8 cmH_2O was required to compensate for the effects of using an HME compared to the use of an HH.[11]

"... reducing artificial airway dead space due to a change in humidification devices appears to be a useful and simple maneuver to control $PaCO_2$ levels."

Morán et al., 2006

EFFECTS ON THE LUNGS AND INSPIRATORY EFFORT

In patients undergoing volume-controlled mechanical ventilation, the use of HH rather than HMEs reduces total dead space without affecting alveolar dead space.[9,10] In a study of 17 patients with acute lung injury or ARDS (per the American-European Consensus Conference criteria), replacing HME with HH led to a significant decrease in $PaCO_2$ levels (40 vs. 46 mmHg, P < 0.001) and a significant improvement in respiratory system compliance (42 vs. 35 mL/cmH_2O, P < 0.001).[9]

Compared with HME, the use of HH reduces inspiratory effort in patients receiving pressure-support ventilation.[11,12] In the study by Girault et al. (2003), the switch to an HME also produced severe respiratory acidosis, which could not be compensated for by the rise in minute ventilation of 1.0 L/min (P < 0.005).[11]

The significantly higher $PaCO_2$ levels observed during the use of HME compared with HH (of 1.5 or 1.9 kPa depending on pressure-support ventilation level, both P < 0.01) also led to significant respiratory discomfort for patients.[11]

KEY POINTS

- Humidification device choice can have significant consequences for ventilator management.
- An HH device permits the use of lung-protective ventilation strategies and can improve respiratory system compliance compared with an HME.
- The use of HH reduces pressure-support requirements and reduces inspiratory effort compared with an HME

INTRODUCTION

Heated humidification reduces the need for recovery of heat and moisture from expired gas and minimizes systemic heat and moisture loss.[2] When air is delivered at Optimal Humidity, rheology and a normal volume of airway secretions are maintained, mucociliary clearance is maximized, and inflammatory reactions from thermal or fluid imbalances in the airway are prevented.[2] Airway patency and lung compliance are supported, preserving lung mechanics.[2] Optimal airway defense by the mucociliary transport system occurs only when inspired gas is at body temperature and pressure, saturated (BTPS).[2]

This review focuses on specific pieces of clinical evidence that demonstrate how the use of active heated humidifiers (HH) compared with passive heat-and-moisture exchangers (HME) influences outcomes in patients undergoing mechanical ventilation.

EVIDENCE FROM THE LITERATURE

REDUCED AIRWAY BURDEN *Thomachot et al., 2001*

- A randomized, crossover study of 10 ICU patients undergoing mechanical ventilation evaluated whether a change in tracheal temperature is a reliable estimate of total respiratory heat loss.
- Patients were ventilated for three consecutive 24-hour periods with HH, hydrophobic HME and hygroscopic HME devices.
- Total respiratory heat loss was significantly less with HH than with both HME devices ($P < 0.01$).
- HH was the best-performing device with regard to maximizing inspired gas relative humidity and absolute humidity.[13]

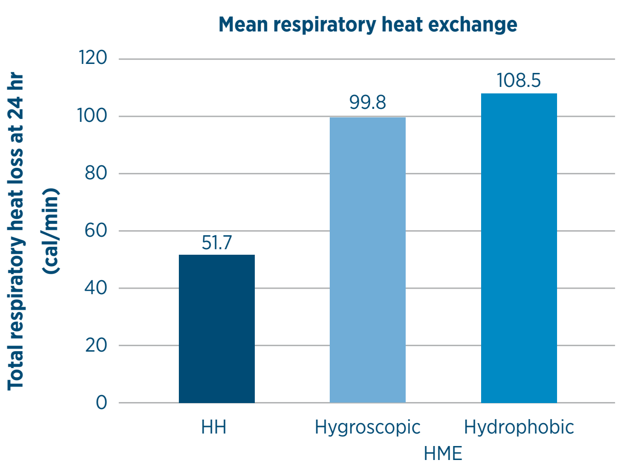


Figure 6: Average respiratory heat loss at 24 hours when using active or passive humidification. Data from Thomachot et al., 2001.[13]

IMPROVED SECRETION QUALITY *Martin et al., 1990*

- A prospective, randomized study of 73 ICU patients undergoing mechanical ventilation compared the safety and efficiency of a filtered HME device and an HH device.
- Thick and tenacious bronchial secretions occurred on 4% of days in the HME group compared with no days in the HH group ($P < 0.02$).
- Tracheostomy tube occlusion occurred on six occasions in six patients in the HME group compared with no occasions in the HH group ($P < 0.01$).
- Hypothermia occurred on 22% of days in the HME group compared with 12% of days in the HH group ($P < 0.01$).
- The authors concluded that HME could not provide adequate humidification and, in patients with minute volumes > 10 L/min, could lead to increased risk of tracheal tube occlusion. They also noted that tracheal instillations alone do not always provide sufficient protection against airway obstructions.[14]

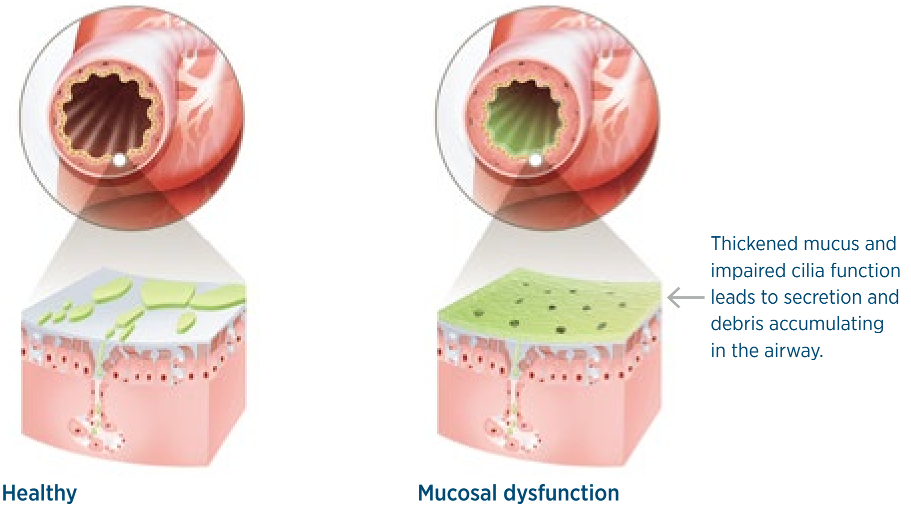


Figure 7: Deviations from Optimal Humidity progressively impair mucociliary transport and can elevate the risk of airway obstruction.

REDUCED AIRWAY OBSTRUCTION IN COVID-19 PATIENTS *GINESTRA ET AL., 2020*

- A report from a multi-center experience in Pennsylvania, USA, before and after implementation of a revised airway management protocol for mechanically ventilated patients with COVID-19.
- At the beginning of the COVID-19 outbreak, the centers began to use HMEs, based on a perception these may reduce healthcare worker exposure.
  - After this change, reports of airway complications increased.
  - A literature review found little evidence in support of HMEs providing protection for healthcare workers.
- A revised protocol mandated the use of HH devices rather than HMEs for all new and existing ventilator circuits. All mechanically ventilated patients across the ICUs were switched from HMEs to HHs within 24 hours.[15]
  - A retrospective review across two of the sites found that prior to the protocol revision, 36% of routinely extubated patients required reintubation within 48 hours and 9.2% of patients had endotracheal tube (ETT) obstruction requiring urgent ETT exchange.
  - After protocol revision, the rate of reintubations decreased to 9% of patients, and the rate of ETT obstructions requiring exchange decreased to 0.71% of patients.
  - There were no reintubations within 48 hours of extubation in the final 19 days of the 6-week study.

KEY POINTS

- The independent nature of HH devices allows them to maximize inspired gas humidity and minimize respiratory heat loss in mechanically ventilated patients when compared to HMEs.
- When compared to an HME, using an HH device for mechanically ventilated patients reduces the incidence of artificial airway occlusion.
- These effects are particularly important for patients with conditions that place them at high risk of airway complications (e.g. COVID-19).

SUMMARY

- The degree to which deviation from Optimal Humidity impacts mucosal function depends on the extent and duration of the deviation, as well as on patient health.

- The independent nature of HH devices allows them to maximize inspired gas humidity and minimize respiratory heat loss in mechanically ventilated patients when compared to HMEs.

- There are currently no published contraindications for heating and humidifying respiratory gases or achieving this with an HH device. There are many contexts where the use of an HME is contraindicated.

- An HH device enables the use of lung-protective ventilation strategies and improves respiratory system compliance compared with an HME.

- When compared to an HME, using an HH device for mechanically ventilated patients reduces the incidence of artificial airway occlusion.

GLOSSARY

AARC

American Association for Respiratory Care.

ABSOLUTE HUMIDITY (AH)

The amount of water vapor present in the air, irrespective of temperature (expressed as mg H_2O/L).

ACIDOSIS

Excess acid in body fluids (low pH < 7.35). Respiratory acidosis can be caused by impaired clearance and subsequent accumulation of carbon dioxide.

ACUTE RESPIRATORY DISTRESS SYNDROME (ARDS)

A syndrome in which the respiratory system fails in one or both of its gas exchange functions: oxygenation and carbon dioxide elimination.

ACUTE RESPIRATORY FAILURE (ARF)

Decreased oxygen uptake which causes low oxygen in the blood (hypoxemia) as well as decreased elimination of carbon dioxide, which may cause high carbon dioxide (hypercapnia).

ALVEOLI

Tiny air sacs in the lungs where oxygen enters, and carbon dioxide leaves the blood stream.

ATELECTASIS

Decreased or absent air in the lung resulting in a loss of lung volume.

BODY TEMPERATURE AND PRESSURE, SATURATED (BTPS)

A state of body temperature, ambient pressure, and saturated water vapor (100% relative humidity).

CILIA

Hair-like structures on the surface of epithelial cells in the respiratory tract.

DEAD SPACE

A volume of gas that does not participate in gas exchange; is common to both the inspiratory and expiratory passages. There are different types of dead space including:

- Alveolar dead space: Alveoli which are ventilated but not perfused, and so cannot supply oxygen to the blood.
- Anatomic dead space: Volume of gas within the conducting zone of the lungs and upper airways (amount of volume that does not enter the alveoli).
- Instrumental dead space (also referred to as apparatus or mechanical): Volume due to presence of equipment that results in re-breathing of gases.
- Physiological dead space: Anatomic and alveolar dead space.

DEW POINT

The temperature at which air is fully saturated with water vapor (100% relative humidity), below which water vapor will condense to form liquid water.

ENDOTRACHEAL TUBE (ETT)

An artificial airway inserted into a patient's tracheobronchial airway through the mouth or nose and passing through the vocal cords. The external end of the tube either connects to a manual resuscitator or a circuit attached to a ventilator.

EXTUBATION

Withdrawal of an endotracheal tube (ETT) from a patient's airway.

FUNCTIONAL RESIDUAL CAPACITY (FRC)

The volume of air that remains in the lungs following a typical expiratory phase; important for keeping the lungs open post-exhalation and continuing passive gas exchange.

HEATED HUMIDIFIER (HH)

A device that actively adds heat and water vapor to inspired gas via external sources.

HEAT AND MOISTURE EXCHANGER (HME)

A passive humidification device that is designed to collect and hold some of the heat and moisture from the patient's exhaled breath, and to return them to the inspired gas mixture during inspiration.

INTUBATION

The insertion of an endotracheal tube (ETT) into the trachea.

ISOTHERMIC SATURATION BOUNDARY (ISB)

The point within the respiratory tract at which inspired air is conditioned to body temperature and 100% relative humidity, and below which air conditioning remains constant.

INVASIVE VENTILATION

The use of an invasive artificial airway to mechanically assist or replace spontaneous breathing when a patient is unable to do so. Often used interchangeably with mechanical ventilation.

MUCOCILIARY TRANSPORT SYSTEM (MTS)

An airway defense system that traps contaminants within mucus and transports these out of the airway through ciliary beating.

NONINVASIVE VENTILATION (NIV)

The delivery of positive pressure ventilatory support without the need for an invasive artificial airway.

OPTIMAL HUMIDITY

The condition to which inspired gas is heated and humidified in the airway. In a normothermic patient, this is 37 °C and 44 mg H_2O/L (BTPS).

PARTIAL PRESSURE OF ARTERIAL OXYGEN (PaO_2)

The part of total blood-gas pressure exerted by oxygen gas – a measure of how much oxygen is dissolved in the blood and how well carbon dioxide can move out of the body.

PARTIAL PRESSURE OF CARBON DIOXIDE ($PaCO_2$)

The partial pressure of carbon dioxide in arterial blood – one of the components measured in the arterial blood gas test and is diagnostic for hypercapnia.

PATENT AIRWAY

An airway that is open and clear.

PEAK INSPIRATORY PRESSURE (PIP)

The highest pressure applied to the lungs during inspiration.

POSITIVE END EXPIRATORY PRESSURE (PEEP)

In the context of a positive airway pressure delivery system, PEEP is the positive airway pressure that is administered during the expiratory phase of the respiratory cycle.

RANDOMIZED CONTROLLED TRIAL (RCT)

Participants are randomly allocated to receive or not receive clinical intervention(s) with the aim of comparing selected outcomes between the groups. This process aims to reduce sources of bias.

RELATIVE HUMIDITY (RH)

The amount of water vapor present in air, expressed as a percentage of the amount needed for saturation at the same temperature.

RESPIRATORY RATE

The number of breaths over a specified period of time.

SATURATION

Describes the state of a gas which is at 100% relative humidity.

TIDAL VOLUME (V_T)

The volume inspired or expired per breath.

TRACHEOSTOMY

Artificial opening through the neck into the trachea.

WORK OF BREATHING (WOB)

The force required to expand the lung against its elastic properties.

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