Humidification Basics

Clinical Evidence Summary

Fisher & Paykel HEALTHCARE

Table of Contents

Reviews: Overview of Heat, Humidification and their Necessity in Respiratory Care

FOR GLOSSARY GO TO **PAGE 16**

CLICK ANY TITLE TO JUMP TO THE PAGE

1. PubMed Al Ashry, H. S. & Modrykamien, A. M. Humidification during mechanical ventilation in the adult patient. *Biomed Res*. Int. 2014, 715434 (2014)
2. PubMed Dawson, J. A., Owen, L. S., Middleburgh, R. & Davis, P. G. Quantifying temperature and relative humidity of medical gases used for newborn resuscitation. *J. Paediatr*. Child Health 50, 24–26 (2014).
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12. PubMed Sottiaux, T. M. Consequences of under- and over-humidification. *Respir. Care Clin. N. Am*. 12, 233–252 (2006).
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Introduction

The airways of neonates and infants are fundamentally different from the adult airway in terms of anatomy and physiology. Therefore, it is vital to have an understanding of these differences and how they impact the delivery of respiratory support to these populations.

The delivery of respiratory gases requires special consideration for several reasons: to ensure maintained function of the mucociliary transport system (MTS), which plays a crucial role in airway defense; to aid in thermoregulation; and to make sure that effective ventilation is provided to these inherently vulnerable patient populations.

UNDERSTANDING THE NEWBORN AIRWAY

The fetal to neonatal transition involves a complex series of physiological events. The first breath generates a high negative inspiratory pressure gradient which overcomes opposing forces allowing the lungs to expand. Lung fluid is shifted into the interstitial tissue where it is gradually removed via the lymphatic system and pulmonary circulation. Lung surfactant, which is secreted near term, lowers tension at the air-liquid interface and reduces the opening pressure needed to aerate the alveoli and prevent alveolar collapse (Saikia & Mahanta, 2019).

Compared to older children and adults, newborns exhibit (Saikia & Mahanta, 2019) unique characteristics; for example:

- **Immature control of respiration**
  Control of respiration can take several weeks – sometimes months – to mature, which may impair the ventilatory response to hypoxia and hypercapnia. High inspired oxygen concentration depresses neonatal ventilation and is associated with retinopathy and bronchopulmonary dysplasia.
- **Small, highly compliant airways**
  They have smaller airways, which leads to a higher resistance to air-flow and subsequent increase in the work of breathing (WOB), particularly during the presence of increased secretions or mucosal edema.
- **Low total lung capacity (TLC) and functional residual capacity (FRC)**
  A highly compliant thoracic wall and poorly compliant lung tissue tends to cause air trapping in the alveoli because of early closure of the terminal airways. Infants are able to modify their respiratory mechanics to maintain small airway patency and increase their FRC by controlling the expiratory flow through the larynx (automatic positive end-expiratory pressure; auto-PEEP) and with the help of the inspiratory muscles post inspiration.

Preterm infants are particularly susceptible to additional respiratory complications, such as:

- During hypoxia, following a brief initial rise, the preterm infant's respiratory rate decreases and can result in apnea.
- They have a poor response to hypercapnia due to their inability to adequately increase tidal volume or respiratory rate.
- Their respiratory system has higher resistance to air-flow, which is further compromised by their extremely small airways.
- Low levels of lung surfactant which can lead to increased surface tension at the air-liquid interface and an increase in the "opening pressure" necessary to aerate the alveoli and prevent alveolar collapse. Exogenous lung surfactant may improve pulmonary ventilation in preterm infants.

AIRWAY PHYSIOLOGY

Many aspects of airway physiology are bypassed or eliminated during invasive ventilation or are compromised with noninvasive ventilation strategies. The MTS provides an extracellular physical barrier on which to trap and neutralize pathogens and contaminants and transport them out of the airway (Williams et al., 1996). This system is the only remaining mechanical airway defense in the intubated patient, and relies on conditioning of inspired gas for optimal function (Figure 1).

The MTS is composed of three layers (Williams et al., 1996):

- A cellular layer – including secretory, absorptive, sensory and ciliated cells
- An aqueous layer (periciliary fluid) – containing a thin 5 µm to 6 µm continuous sheet of low-viscosity fluid
- A viscoelastic gel layer (mucus) – composed of 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.

The temperature and humidity of inspired gas are crucial for optimal functioning of this transport system, as the delivery of suboptimal heat and moisture causes a progressive slowing of the MTS and an inefficient airway defense (Williams et al., 1996).

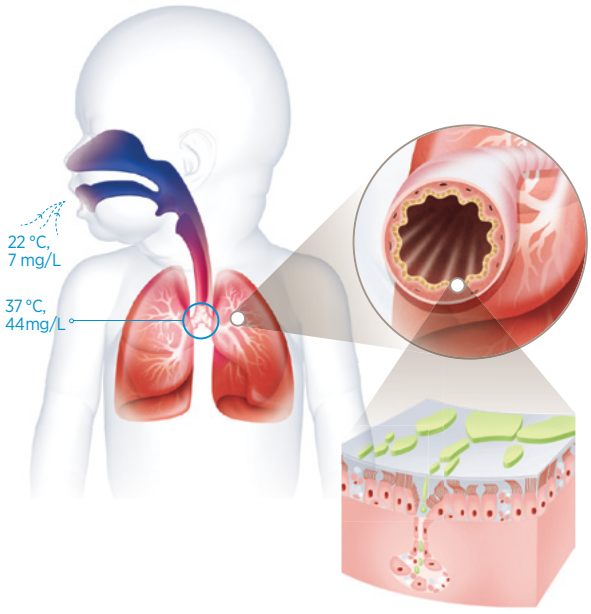

Figure 1. The mucociliary transport system is key for natural airway defense and conditioning, but relies on the heat and humidity of inspired air to prevent dysfunction. The three layers of this system include the cellular layer (pink), aqueous layer (blue) and mucus (green). Adapted from Williams et al. (1996).

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/L at 37 °C). The level at which inspired air reaches this point is called the isothermic saturation boundary. It is located around the level of the main stem bronchi in the adult during normal quiet breathing of room air, but its position can vary with the heat and moisture content of inspired air and breathing patterns (Schulze, 2007).

Consequently, a temperature and humidity gradient exists along the airway, from the ambient temperature and humidity at the airway opening to the core temperature and 100% relative humidity at the isothermic saturation boundary (ISB). The mucosa above the ISB, which was cooled and dried 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. Consequently, there is a direct and dynamic relationship between expired and inspired humidity (Schulze, 2007; Williams et al., 1996).

MAINTAINING BALANCE DURING RESPIRATORY SUPPORT

During invasive ventilation, intubation bypasses the upper airway and gas is delivered directly to the lower airway with minimal opportunity for normal conditioning. Although most research on airway thermodynamics has been conducted in adults (Figure 2), the same principles apply to neonates and infants.

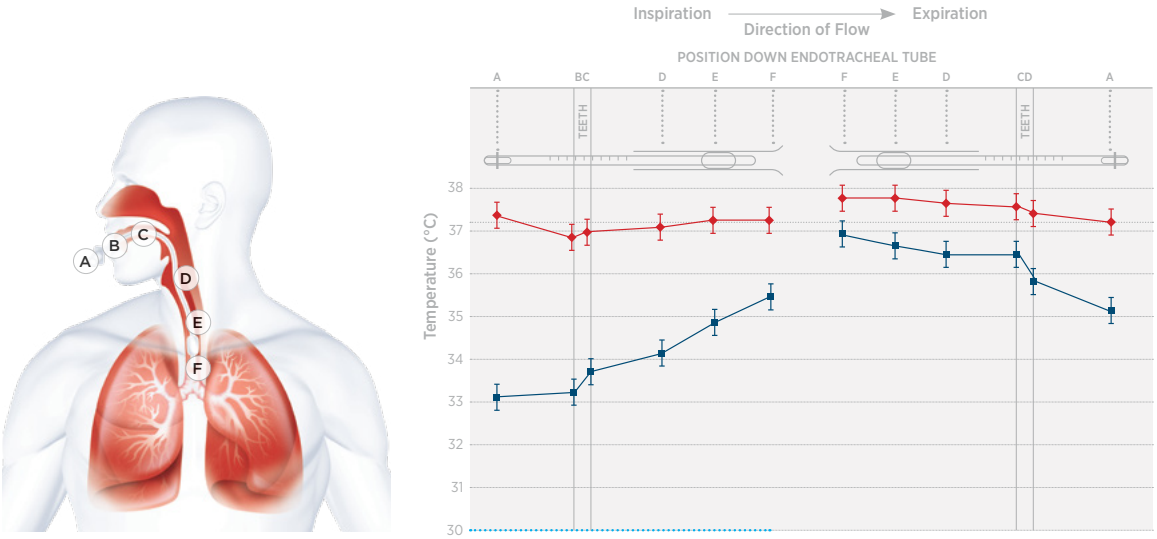

Figure 2. Changes in temperature along the intubated airway of an invasively ventilated patient during inspiration and expiration. The red line and circles represent the profile when the inspired gas temperature at the circuit Y-piece was set to 37 °C. The blue line and squares represent the profile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

Airway workload and water loss are neutral only when the inspired gas is at body temperature and saturated. As the mucosa of an intubated patient has limited ability to warm inspired air and increase water content, inspired air at a temperature lower than body temperature and not fully saturated with water vapor increases workload and results in a net water loss from the airway. Therefore, to provide optimal conditions for mechanical ventilation lasting more than a few hours, inspired gas should be at body temperature and saturated (Ryan et al., 2002).

In infants, the structure and function of the various components of their intricate airway system may easily become disturbed when the inspired gas is inadequately conditioned. Invasive ventilation with cold, dry gas has been shown to cause a mean 1.4 °C decrease in rectal temperature within 1 hour in neonates (Fonkalsrud et al., 1980). There is therefore a strong physiologic rationale for delivering the inspiratory gas at or close to core body temperature and saturated with water vapor to neonates and infants who receive mechanical ventilatory assistance (Schulze, 2007).

KEY POINTS

- Neonates and infants are inherently compromised as they have structurally smaller and more compliant airways, immature respiratory control and an immature MTS.
- The MTS 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 isothermic saturation boundary by numerous mechanisms.
- Respiratory support methods are designed to support a physiologically normal airway while aiding gas exchange and oxygenation.

Core Principles of Heat and Humidity

This section 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. This is especially important for neonates and infants, who have limited energy reserves with which to maintain physiological conditions.

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 measured by two methods (Schulze, 2007):

- **Absolute humidity** (AH) refers to the actual amount of water vapor in a volume of gas irrespective of temperature, and is expressed as milligrams per liter (mg/L).
- **Relative humidity** (RH) refers to the amount of actual water vapor within a gas relative to the capacity of the gas for water at a given temperature, and is expressed in percentage form.

WATER VAPOR 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. When air is saturated, i.e. at 100% RH, the air is carrying its maximum capacity of water vapor for the given temperature. When saturated air is heated, its capacity to hold water increases – and although absolute water content is unchanged, this increase in capacity means relative humidity decreases (< 100% RH). Unsaturated air absorbs moisture until it reaches a new equilibrium (i.e. it becomes fully saturated). Conversely, when saturated air is cooled, its capacity for water vapor decreases and condensation enables a loss of water vapor content so the air can reach a new equilibrium of full saturation at the lower temperature (Williams et al., 1996).

The total energy of air is composed of sensible heat (reflected in the air temperature) and latent heat (reflected in the water mass). Consequently, moist air contains more energy than dry air. Changing gas temperature without an alteration of water content has only a small effect on the total energy of the gas compared to the uptake of energy from adding water vapor content. Altering the temperature of water requires approximately four times as much energy as changing the temperature of air. Therefore, the buffering provided by the water lining of the mucosa protects the mucosa from extremes of dry air temperature (Williams et al., 1996). At core temperature (37 °C) and 100% RH, respiratory gas has 44 mg/L absolute water content, sometimes referred to as a state of body temperature and pressure, saturated (BTPS).

WHAT IS THERMOREGULATION?

Thermoregulation is a process that allows the body to maintain its core internal temperature even when the surrounding temperature is very different. Normothermia refers to the "normal range" of body temperature, which in infants lies between 36.5 °C and 37.5 °C. Hyperthermia occurs when body temperature surpasses this upper limit, and degrees of hypothermia occur below this lower limit (Figure 3) (WHO Safe Motherhood, 1993).

Hypothermia is a well-recognized and significant contributor to morbidity and mortality in newborn infants. An infant's thermal control is limited compared to that of an adult, who can maintain body heat in temperatures as low as 0 °C. For the full-term infant, this range is between 20 °C and 23 °C (WHO Safe Motherhood, 1993).

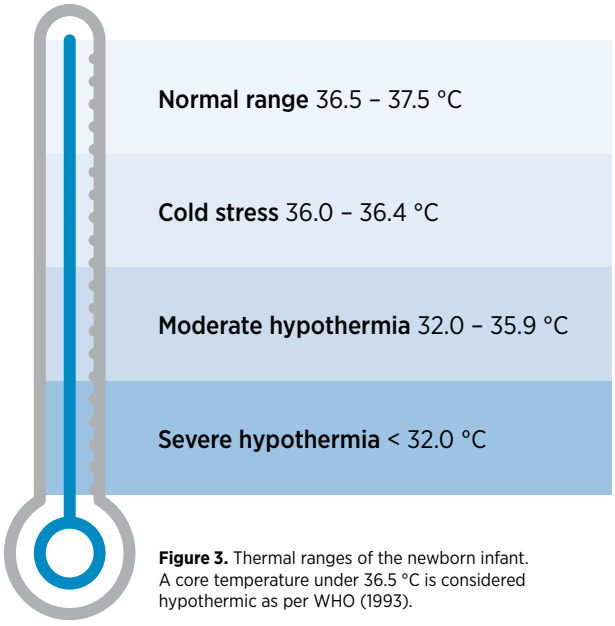

Figure 3. Thermal ranges of the newborn infant. A core temperature under 36.5 °C is considered hypothermic as per WHO (1993).

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 (Ryan et al., 2002). Airway workload and airway water loss increase linearly as the inspired gas decreases from these optimal levels (Ryan et al., 2002).

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

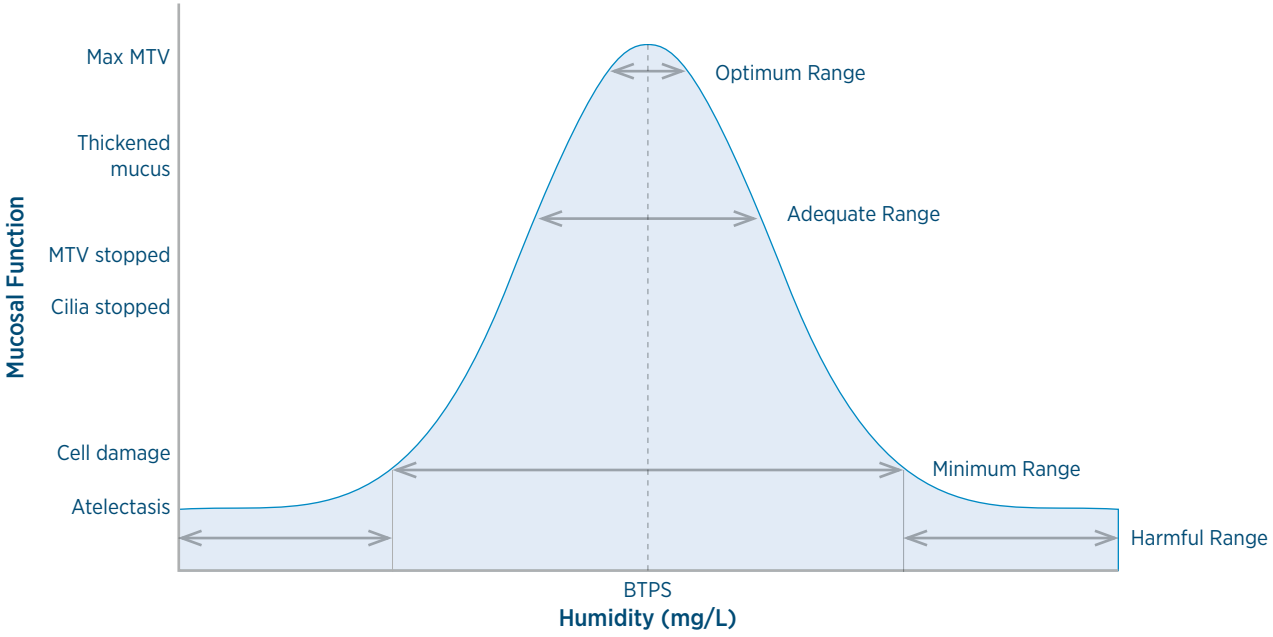

Figure 4. Mucosal function vs. inspired humidity curve. Image adapted from Williams et al. (1996).
Abbreviations: BTPS, body temperature atmospheric pressure and saturated with water vapor; MTV, mucociliary transport velocity.

Figure 4 is a graphic representation of mucosal function vs. inspired humidity, which 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). Inspired gases that are higher or lower than core temperature and < 100% RH may be harmful to mucosal function. Both dry and excess moisture conditions slow and then halt mucociliary transport. Re-humidification after mucociliary transport has stopped for 3 hours was found to result in extensive inflammation and sloughing of the airway mucosa (Williams et al., 1996).

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. The curve is probably unique for each individual as there is likely to be intra- and inter-individual variation in mucosal function under the same humidity conditions; however, the shape of the curve should be similar between individuals (Ryan et al., 2002).

KEY POINTS

- Maintenance of heat and water balance in inspired air is critical for infants as they have limited energy reserves with which to maintain physiologic conditions.
- 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.

Methods of Heated Humidification

There is a strong rationale for delivering inspiratory gas at or close to core body temperature and saturated with water vapor (optimal humidity) to intubated infants. This section outlines and compares the methods available for heating and humidifying respiratory gases and their applicability to neonates and infants.

METHODS OF HEATING AND HUMIDIFYING AIR

Medical gases and room air do not deliver the optimal humidification necessary to maintain physiological conditions in neonates and infants.

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).

Medical gases	Room air	Optimal humidity
23.3 ± 0.9 °C	23.4 ± 0.9 °C	37 °C
2.1 ± 1.1% RH	5.4 ± 0.7% RH	100% RH

Humidification of respiratory gases prior to airway delivery is currently achieved by either active humidification using a heated humidifier (HH) or passive humidification using a heat and moisture exchanger (HME). Both act to warm gas and add water content, thereby adding energy (Al Ashry & Modrykamien, 2014; Schulze, 2007).

KEY FEATURES OF ACTIVE VERSUS PASSIVE HUMIDIFIERS

Active HHs enable air to be transported over a heated water reservoir. The water within the chamber evaporates, adding water vapor into the gas path. HHs are 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 (Al Ashry & Modrykamien, 2014; Schulze, 2007). Although concerns have been raised about the risk of nosocomial infection with inspiratory gas conditioning, there is no evidence that conditioning to core body temperature and full water vapor saturation promotes nosocomial respiratory infection (Schulze, 2007). Water vapor itself cannot transmit an infection (Schulze, 2007), as water molecules are many times smaller than bacteria and viruses.

Passive HMEs (also called artificial noses) mimic the humidifying action of the nasal cavity. HMEs are placed in the inspiratory limb of the circuit, between the Y-piece and the patient's airway (Schulze, 2007). These devices contain a condenser element which retains moisture on exhalation, so that when the next inspired breath passes through it may passively gain heat and humidity. Unlike HHs, this means the conditioning ability of an HME relies on the provision of heat and moisture by the patient (Al Ashry & Modrykamien, 2014).

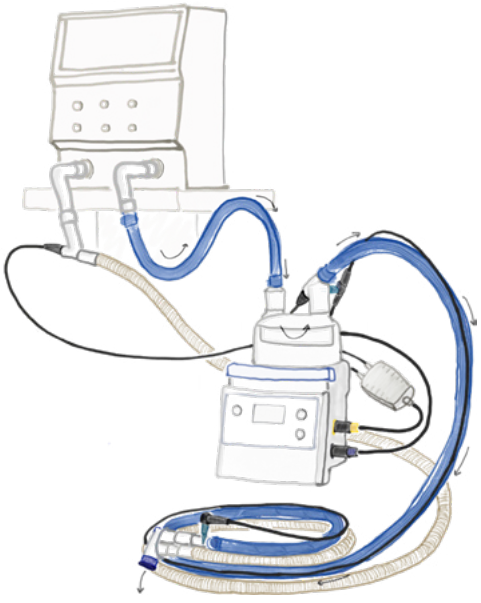

Figure 5. Active humidifiers add heat and humidification to medical gases prior to inspiration. Arrows indicate the flow of gas to the patient for inspiration through the inspiratory circuit (blue).

Table 2 summarizes recommendations by the American Association for Respiratory Care (AARC) for humidification during invasive and noninvasive respiratory support across all populations (Restrepo & Walsh, 2012). The AARC recommends the use of an HH over an HME for noninvasive ventilation based on data indicating improved patient comfort and tolerance. Notably, these guidelines also stipulate HMEs should be avoided in patients with small tidal volumes, such as neonates and infants.

Table 2. American Association for Respiratory Care recommendations for humidification during invasive and noninvasive respiratory support (Restrepo & Walsh, 2012).

Active humidification (HHs)	Passive humidification (HMEs)
• HHs are recommended for patients undergoing invasive ventilation. • Active humidification is recommended for noninvasive respiratory support. • This type of humidification may improve patient adherence and comfort. • It is suggested that the HH device achieves a humidity level between 33 mgH_2O/L and 44 mgH_2O/L and gas temperature between 34 °C and 41 °C at the circuit Y-piece, and a relative humidity of 100%.	• Passive humidification is not recommended for noninvasive ventilation. • HMEs are not recommended in patients with low tidal volumes (such as neonates and infants, or when lung-protective ventilation strategies are used) due to addition of dead space. • It is suggested that the HME provides a minimum of 30 mgH_2O/L.

CONSIDERATIONS FOR NEONATES AND INFANTS

The safety and effectiveness of HMEs in treating the infant population is not well established and they have been shown to add variable resistance and dead space to the circuit, which may increase ventilation requirement and partial pressure of carbon dioxide ($PaCO_2$), as well as the risk of respiratory acidosis (Restrepo & Walsh, 2012; Schulze, 2007).

A randomized clinical trial (RCT) comparing HH to HME in children with tracheostomies found that short-term HH use (20 hours, n = 15 children) achieved lower WOB (40.5 ± 16.7 breaths/min vs. 42.5 ± 18.6 breaths/min; P = 0.04) and respiratory examination scores (2.5 ± 2.0 vs. 3.7 ± 2.6; P < 0.001) compared to HME use (McNamara et al., 2014).

During long-term use (10 weeks, n = 21), HH was associated with a lower incidence of adverse clinical events compared to HME (5 vs. 11 events; P = 0.008). There were also fewer treatment failures and/or study withdrawal during HH use (0 vs. 3). However, there were no differences between treatment groups in breathing frequency, oxygenation, or WOB, as measured by the clinical examination score (McNamara et al., 2014).

The authors concluded that HH improved patient comfort and reduced the frequency of complications, compared to HME. However, given the small size of the study, these results require confirmation in a larger, appropriately powered clinical trial.

KEY POINTS

- The addition of heat and humidification to gases delivered during respiratory support is beneficial for patients, regardless of 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.
- For the infant population, HHs are typically preferred over HMEs due to concerns about added dead space, increased resistance to flow and to maximize energy conservation.

Heat and Humidification in Clinical Practice

There are no contraindications to heating and humidifying inspired gases; however, the choice of the device used requires consideration (Restrepo & Walsh, 2012). The various methods of respiratory support aim to provide different levels of humidity, based on the degree to which normal conditioning processes are compromised or bypassed. Available respiratory support options include positive pressure ventilation during resuscitation, invasive ventilation, continuous positive airway pressure (CPAP) and nasal high flow (NHF) therapy.

Table 3. Heat and humidification has a role across all levels of respiratory support for neonates and infants. The current clinical evidence across these therapy areas varies from standard practice to emergent and ongoing.

	Resuscitation	Invasive ventilation	Noninvasive ventilation (NIV)	
Current status	Support for the use of heat and humidification in the setting of resuscitation is emerging.	The AARC states that use of humidification is compulsory for invasive ventilation (Restrepo & Walsh, 2012).	While not mandated in clinical guidelines (Restrepo & Walsh, 2012), heat and humidification during NIV is supported by clinical data and plays a key role in noninvasive therapies such as CPAP and NHF.	
Evidence	*Meyer et al. (2018):* Meta-analysis of published randomized trials using heated humidified gas compared to cold, dry gas in preterm infants immediately after birth and during transport to the neonatal unit found that infants given heated and humidified gas had higher rates of admission normothermia. • Admission hypothermia was reduced by 36%. • Mortality and measures of respiratory outcome were not significantly different, although there was a trend to improvement in all respiratory measures assessed.	When mechanical ventilation is extended beyond several days, adequate conditioning of respiratory gases becomes increasingly crucial to maximize mucociliary function and prevent retention of secretions.	**CPAP** *Lellouche et al. (2009):* CPAP with heated, humidified gas was better tolerated and more comfortable than CPAP with no humidification in a study of 12 healthy subjects. • Comfort, assessed on a 0 to 10 visual scale, was significantly lower when no humidification was used compared to the use of CPAP with humidified air ($P < 0.005$).	**NHF** *Woodhead et al. (2006):* Patients in NICU who received humidified NHF post extubation had a more normal mucosa, lower respiratory effort scores and less need for reintubation ($P < 0.05$).
Strength of evidence	***Emerging with ongoing research***	***Mandated by clinical guidelines***	***Well supported by literature and recommended by clinical guidelines***	

KEY POINTS

- The conditioning of respiratory gases is essential for invasive ventilation. Use of HH for heating and humidification is standard practice for neonates and infants.
- HH is widely recommended and is standard practice for noninvasive respiratory support, and plays an integral role in established neonatal and infant therapies.

The Importance of Heating and Humidifying Respiratory Gases for Patient Outcomes

Considerable energy is used during the addition of heat and moisture to inspired air. This energy requirement is of particular relevance considering the limited energy supplies of neonates and infants, who are unable to continue conditioning inspired gas over prolonged periods. Providing artificially conditioned respiratory gases at around body temperature and 100% saturation minimizes the energy demand placed on the infant (Ryan et al., 2002; Sottiaux, 2006). Clinical evidence strongly supports heating and humidifying inspiratory gases for infants in need of respiratory support to ensure energy demand is minimized, complications are reduced and positive outcomes are achieved in this vulnerable patient group.

ENERGY USED BY THE NEONATE TO HEAT AND HUMIDIFY COLD, DRY GASES TO PHYSIOLOGICAL CONDITIONS HAS BEEN APPROXIMATED TO 40 KJ/KG/DAY, 85% OF WHICH IS USED FOR HUMIDIFICATION.
(DAWSON ET AL., 2014)

HEAT AND HUMIDIFICATION IMPROVES PATIENT OUTCOMES

The delivery of heated and humidified gas to infants requiring respiratory support has well recognized, clinically relevant benefits for respiration and mucociliary function.

Woodhead et al. (2006): Comparing two methods of delivering high-flow gas therapy by nasal cannula following endotracheal extubation: a prospective, randomized, masked, cross-over trial.

- In their prospective RCT, Woodhead and colleagues demonstrated that infants who received heated and humidified NHF therapy immediately after extubation had significantly lowered respiratory effort scores, a more normal mucosal function, and a lower requirement for reintubation compared with infants who received standard (unheated, unhumidified) high-flow therapy after extubation.

Greenspan et al. (1991): Airway responsiveness to low inspired gas temperature in preterm neonates.

- Greenspan and colleagues observed that infants exposed to short periods of ventilation with inspired gas at room temperature (24 °C to 25 °C) and humidity (45% to 50% RH) had significant decreases in dynamic pulmonary compliance (small airway reactivity) and conductance (large airway reactivity) at 5 minutes after the exposure.
- This negative impact of low temperature and low humidity on airway reactivity was accompanied by increases in the WOB and peak trans-pulmonary pressure change.
- All of these parameters returned to baseline values within 30 minutes of restarting heated humidification.
- This study highlights that significant airway reactivity occurs in response to relatively small changes in temperature and humidity of inspired air in stable preterm neonates receiving mechanical ventilation. Consequently, protocols and equipment used in neonatal ventilatory care must ensure that the gas delivered to neonates during mechanical ventilation is adequately heated and humidified.

HEAT AND HUMIDIFICATION REDUCES THE RISK OF COMPLICATIONS

Risks associated with delivering inspired gases that are not heated and humidified include increased respiratory complications and suboptimal clinical outcomes (Tarnow-Mordi et al., 1989).

Tarnow-Mordi et al. (1989): Low inspired gas temperature and respiratory complications in very low birthweight infants.

- Tarnow-Mordi and colleagues investigated the effect that temperature and humidity of inspired gases had on the incidence of pneumothorax and chronic lung disease in neonates receiving mechanical ventilation.
- Infants were grouped according to whether the temperature of inspired gases in the first 96 hours was ≤ 36.5 °C (low) or > 36.5 °C (high), as well as according to birth weight (≥ 1500 g and < 1500 g).
- The findings for infants weighing < 1500 g are summarized in Table 4.

Table 4. Clinical outcomes in neonates with a birth weight of < 1500 g.
FiO_2 = fraction of inspired oxygen required to maintain adequate saturation; NS = not significant.
[a] = a measure of chronic lung disease; mean values ± standard deviation.

Outcome	Inspired gas temperature in the first 96 hours		P-value
	Low (≤ 36.5 °C), n = 28	High (> 36.5 °C), n = 60	
Deaths (%)	27	16	NS
Pneumothorax (%)	43	13	0.006
FiO_2 in survivors at 29 days[a] (%)	37.2 ± 20.5	27.5 ± 9.4	< 0.001

- There was no significant difference in clinical outcomes (deaths, pneumothorax, chronic lung disease) for infants weighing ≥ 1500 g at birth when the inspired gas was at low temperatures (≤ 36.5 °C) compared with high temperatures (> 36.5 °C) during the first 96 hours.
- However, clinical outcomes (pneumothorax, chronic lung disease) were significantly worse for infants weighing < 1500 g when the inspired gas temperature was ≤ 36.5 °C compared with > 36.5 °C.

Fonkalsrud et al. (1980): Reduction of operative heat loss and pulmonary secretions in neonates by use of heated and humidified anesthetic gases.

- A study comparing two regimens, heated and humidified ventilation (HHV; 100% relative humidity at 32 °C to 37° C) and standard nonconditioned ventilation (SV; dry gases at room temperature 22 °C to 24 °C), in infants undergoing major surgical procedures observed a significantly lower loss of body heat during anesthesia in infants who received HHV.
- The mean rectal temperature of the infants given HHV decreased by 0.2 °C ± 0.6 °C during the first hour of anesthesia, whereas the mean temperature decreased by 1.4 °C ± 0.9 °C during the first hour in the infants given SV ($P < 0.01$).
- At the end of anesthesia, the mean temperature in SV infants was 1.2 °C ± 1.2 °C less than that recorded at the start; by contrast, there was a 0.3 °C ± 0.9 °C gain in temperature for the HHV infants during the same period (Figure 6).
- Postoperative atelectasis or pneumonia occurred in fewer infants given HHV.
- Pulmonary secretions in general were more voluminous, tenacious and difficult to remove via endotracheal suction immediately after operation in the infants given SV (however, objective quantification of these observations was not undertaken).

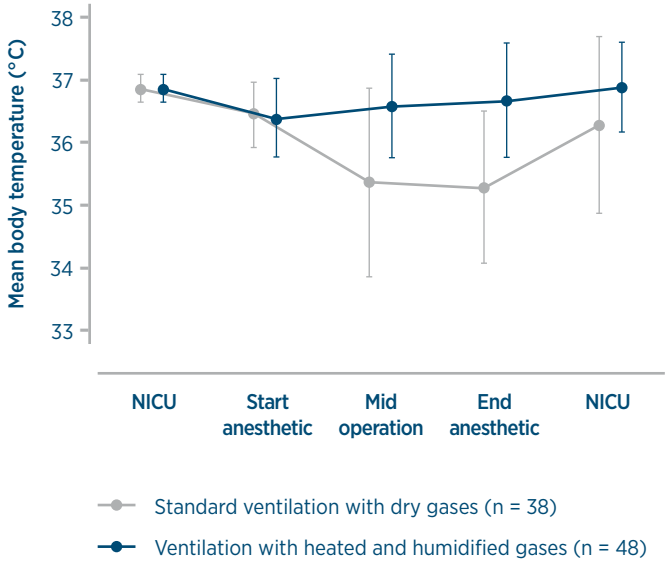

Figure 6. Changes in body temperature (mean ± SD) from time of departure from neonatal intensive care unit (NICU) until return in neonates undergoing general anesthesia for repair of major malformations. Image adapted from Fonkalsrud et al. (1980).

KEY POINTS

- The intent of artificially conditioning respiratory gases with heat and humidification is to reproduce, as much as possible, the conditions existing in a normal airway. Of particular importance for neonates and infants, the pre-conditioning of respiratory gases also conserves energy and promotes normothermia.
- The use of heated humidification for infants receiving respiratory support is associated with improvement of respiratory effort, mucosal function (assisting airway defense) and airway compliance, as well as reduced WOB.
- The use of heated humidification may reduce the risk of respiratory morbidities, reduce airway obstruction, improve the viscosity of pulmonary secretions while also reducing their volume, and limit heat loss during surgical procedures.

SUMMARY

- Special consideration is required when initiating respiratory support in neonates and infants, as this patient group has structurally smaller airways, immature respiratory mechanics and limited airway defense compared with older children and adults.

- Delivering heated, humidified inspiratory gases is critical for infants as it helps to maintain heat and water balance, as well as energy reserves.

- The benefit of heat and humidification is maximized when inspired air is closest to normal physiological conditions (37 °C, 44 mg/L).

- The level of impact that deviation from optimal humidity has on the respiratory system is dependent on the extent of deviation from optimal humidity, the duration of deviation, and individual patient health.

- Currently there are no contraindications for heating and humidifying gases for respiratory support. The use of heated humidification is a standard requirement for invasive ventilation as per clinical practice guidelines, and widely recommended for noninvasive ventilation.

- The use of heated humidification has been associated with improvements to respiratory function, including improved airway compliance; mucosal function; and WOB in infants requiring respiratory support.

GLOSSARY

Note: In common language and indeed in many scientific texts, the terms “baby”, “preterm infant”, “infant” and “neonate” are often used interchangeably. Where possible, we refer to the FDA nomenclature; however, it is acknowledged that there is some overlap and grouping of populations under common language terms, which is fair and reasonable.

AARC

American Association for Respiratory Care

ABSOLUTE HUMIDITY (AH)

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

ACUTE RESPIRATORY FAILURE (ARF)

Inability of the respiratory system to maintain oxygenation and eliminate carbon dioxide

ATELECTASIS

Incomplete expansion of a portion of the lung or the whole lung

BODY TEMPERATURE AND PRESSURE, SATURATED (BTPS)

A volume of gas which is at both body temperature and ambient pressure, and saturated with water vapor. Equivalent to core temperature and 100% relative humidity (37 °C, 44mg/L)

CHILD

Defined by the FDA as between 2 years and < 12 years of age

CILIA

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

CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)

A technique of respiratory therapy in which airway pressure is maintained above atmospheric pressure throughout the respiratory cycle by pressurization of ventilatory circuit

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**
  Volume of gas ventilating unperfused alveoli that has no blood perfusion (shunt or pulmonary embolism)
- **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)
- **Mechanical dead space**
  Expired air that is re-breathed through connecting tubing
- **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)

A tube inserted through the mouth or nose into the trachea to maintain an unobstructed airway. Most commonly used to ventilate lungs or administer therapeutics

EXTUBATION

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

FRACTION OF INSPIRED OXYGEN (FIO_2)

The proportion of oxygen in the air that is inspired

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

GESTATIONAL AGE (GA)

Gestation is the period of time between conception and birth

HEATED HUMIDIFIER (HH)

A device used for active respiratory humidification in which water vapor and thermal energy are actively added to condition gases prior to inspiration

HEAT AND MOISTURE EXCHANGER (HME)

A device that constitutes the passive form of respiratory humidification which retains heat and moisture from the expired breath to return on inspiration

INFANT

Defined by the FDA as between 29 days and < 2 years of age

INTUBATION

The insertion of an ETT or tracheostomy tube 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. Used interchangeably with mechanical ventilation

MUCOCILIARY TRANSPORT SYSTEM (MTS)

Airway defense system which traps and neutralizes contaminants within mucus, before beating of cilia propagates it out of the airway

NASAL CONTINUOUS POSITIVE AIRWAY PRESSURE (NCPAP)

Used interchangeably with CPAP, indicating a mode of noninvasive ventilation delivered via a nasal interface

NEONATE

Defined by the FDA as between 0 and 28 days postnatal age

NASAL HIGH FLOW (NHF)

A mode of noninvasive therapy delivering high flows of a blend of heated and humidified air and oxygen through a nasal cannula

NEONATAL INTENSIVE CARE UNIT (NICU)

A hospital facility providing intensive nursing and medical care for critically-ill newborn infants

NONINVASIVE VENTILATION (NIV)

The delivery of respiratory/ventilatory support without the need for an invasive artificial airway

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

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

PEDIATRIC INTENSIVE CARE UNIT (PICU)

A hospital facility providing intensive nursing and medical care for critically-ill infants

PEAK INSPIRATORY PRESSURE (PIP)

The highest pressure applied to the lungs during inspiration

POSTNATAL AGE

Time elapsed after birth

PRETERM:

An infant born < 37 weeks gestation, regardless of weight.

They may be further divided:

- **Moderate to late preterm:** (32 to < 37 weeks gestation)
- **Very preterm:** (28 to < 32 weeks gestation)
- **Extremely preterm:** (< 28 weeks gestation)

RANDOMIZED CONTROLLED TRIAL (RCT)

A type of scientific (often medical) study design where participants are randomly allocated to receive or not receive clinical intervention(s) with the aim of comparing selected outcomes between these groups. Random allocation aims to reduce certain sources of bias

RESPIRATORY DISTRESS SYNDROME (RDS)

A lung disease of the newborn, most frequently occurring in premature infants, caused by abnormally high alveolar surface tension as a result of lung surfactant deficiency. Also known as Hyaline membrane disease (HMD)

RESPIRATORY RATE

The number of breaths over a specified period of time

RELATIVE HUMIDITY (RH)

The amount of actual water vapor within a gas relative to the capacity of the gas for water at a given temperature, expressed as a percentage

TIDAL VOLUME (VT)

The volume inspired or expired per breath. The amount of gas delivered to a patient in one breath

WORK OF BREATHING (WOB)

The force required to expand the lung against its elastic properties

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