

Humidification Basics

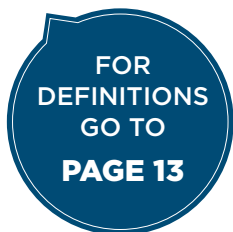
Infant Care

Clinical Paper Summaries



Table of Contents

	PG
OPTIMAL HUMIDITY	
S1 Humidification and airway function (Williams)	2
S2 Humidification and airway thermodynamics (Ryan)	4
S3 Humidification and pulmonary function (Greenspan)	6
S4 Humidification and respiratory complications (Tarnow-Mordi)	7
OPTIMAL HUMIDITY BASICS	9
QUICK GUIDE TO HUMIDIFICATION	10
INFANT AIRWAYS	11
INFANT INVASIVE VENTILATION	12
GLOSSARY/REFERENCES	13





OPTIMAL HUMIDITY.

CLINICAL IMPACT OF INADEQUATE HUMIDITY

1. [PubMed](#) [Williams R](#), Rankin N, Smith T, Galler D, Seakins P. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. *Critical care medicine*. 1996 Nov 1;24(11):1920-9.
2. [PubMed](#) [Ryan SN](#), Rankin N, Meyer E, Williams R. Energy balance in the intubated human airway is an indicator of optimal gas conditioning. *Critical care medicine*. 2002 Feb 1;30(2):355-61.
3. [PubMed](#) [Greenspan JS](#), Wolfson MR, Shaffer TH. Airway responsiveness to low inspired gas temperature in preterm neonates. *The Journal of pediatrics*. 1991 Mar 31;118(3):443-5.
4. [PubMed](#) [Tarnow-Mordi WO](#), Reid E, Griffiths P, Wilkinson AR. Low inspired gas temperature and respiratory complications in very low birth weight infants. *The Journal of pediatrics*. 1989 Mar 31;114(3):438-42.



Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa

AIM

To review the physics of heat and moisture exchange in the airway, the structure and function of the airway mucosa, and the effects of humidity on function, and to use existing literature to create a model of the relationship between the humidity and temperature of inspired gases and mucosal function.

DISCUSSION

LITERATURE REVIEW

Physical principles: Within the airway heat and moisture can be lost to inspired air, recovered from expired air or supplied from systemic reserves. The airway mucosa reaches a natural equilibrium when inspired air is at core temperature and 100% RH. Any other conditions result in the gain or loss of heat and/or moisture from the airway.

Mucosal structure: The airway mucosa consists of a cellular layer (consisting of cilia), an aqueous layer and a viscoelastic gel layer (mucus). The interaction of these layers forms the basis of the Mucociliary transport system (MTS), and each is affected by levels of temperature and moisture. Changes in the properties of any component of the MTS have a direct effect on mucociliary transport, and mucociliary dysfunction is one of the earliest indicators of inadequate heat and moisture delivery to the airway. The MTS functions optimally under conditions of core temperature and 100% relative humidity. Either low or high heat and moisture content of inspired gases slows mucociliary transport. The MTS is the final mechanical defence system for the airway.

Respiratory tract function: Many of the major functions of the respiratory tract are bypassed or eliminated during endotracheal intubation, and a number are affected by the temperature and humidity of inspired gas. The airways condition inspired gases to body temperature and 100% relative humidity, a process that is usually completed in the pharynx and trachea; the point at which this occurs is termed the Isothermic saturation boundary (ISB). During each breath, some of the heat and moisture given up to inspired air by the airway is recovered on expiration. Variations in the humidity of inspired gases can have a negative effect on lung mechanics by altering airway patency and lung compliance, which in turn impairs gas exchange.

Mucosal function model: Data from the literature allow the sequence of airway dysfunction occurring in response to heat and moisture deficit to be predicted. In this model mucosal function varies according to the magnitude of the change in the temperature and humidity of inspired gases from the ideal (body temperature and 100% relative humidity). Details of the changes in mucosal and respiratory function across different inspired humidity ranges are described in the table.



Mucosal and respiratory function	Inspired humidity range			
	Optimum	Adequate	Minimal	Harmful
Mucociliary transport	Maximised	Reduced	Ceases locally	Ceases in the proximal airway
Mucosal cells	Healthy	Healthy; challenged osmotically and thermally	Severely challenged osmotically and thermally	Irreversibly and extensively damaged
Heat/moisture recovery	Maximised	Reduced	Markedly reduced	Markedly reduced
Lung inflation	Maximised	Normal	Reversibly impaired	Impaired
Gas conditioning	Maximised	Normal	Reversibly impaired	Impaired
Airway patency	Maximised	Normal	Reversibly impaired	Impaired

Other factors in the model are exposure time, inspired gas temperature and patient health. With respect to exposure time, the longer the airway is exposed to a humidity and/or temperature deficit, the more difficult it becomes for systemic reserves to overcome this deficit. Thus, systemic reserves will become depleted and progressive mucociliary dysfunction occurs.

CONCLUSION

Inspired gas at conditions of core temperature and 100% relative humidity optimises mucosal function. Under these conditions, normal rheology and volume of airway secretions is maintained, mucociliary clearance is maximised, and inflammatory reactions to thermal injury or fluid imbalance are prevented. Preservation of normal mucosal function preserves lung mechanics by sustaining airway patency and lung compliance. Delivery of inspired gas at anything other than core temperature and 100% relative humidity results in suboptimal mucosal function. The degree of damage depends on the extent of the temperature and humidity deficit, and the duration of exposure.

KEY POINTS

- In mechanically ventilated patients, gas inspired at core temperature and 100% relative humidity optimizes mucosal function.
- Any reduction in either the temperature or humidity of inspired gases has a negative effect on the mucociliary transport system.
- The mucociliary transport system needs to be functioning optimally to maintain airway patency and lung compliance, thus preserving normal lung mechanics.
- The magnitude of the damage depends on the extent of the temperature and humidity deficit, and the duration of exposure to these deficits.

Wolters Kluwer Pharma Solutions

Independently produced by Wolters Kluwer Health - Adis International Ltd
World leaders in impartial pharmacoevaluation



Energy balance in the intubated human airway is an indicator of optimal gas conditioning

AIM

To examine the inspired gas condition that would be thermodynamically neutral down the ETT in intubated patients, and to assess the contribution of the ETT to airway heat and water balance.

METHOD

This prospective, block-randomised, observational study enrolled adult patients in a single general adult intensive care unit. Patients with no pre-existing lung disease who were orally intubated and mechanically ventilated for at least 12h were included. Patients were ventilated with an assist control mode using a Seimens Servo 300 or 900C ventilator and inspired gas was conditioned using a HH (MR730; Fisher and Paykel Healthcare). Each patient was given four different saturated gas conditions to breathe, 30°C (30 mg/L), 34°C (38 mg/L), 37°C (44 mg/L) and 40°C (50 mg/L), in a randomised sequence.

Inspired and expired gas temperature and humidity, and the temperature gradient down the ETT, were measured using an oesophageal temperature probe (Mon-a-therm; Mallinckrodt) that was inserted to the level of the carina and left in place for the duration of the study. Temperature from the probe was recorded using an electronic thermometer (TM 101; Fisher & Paykel Healthcare) and inspired and expired gas humidity was monitored using a fast-acting infrared hygrometer (Fisher & Paykel Healthcare). From these measurements the inspired gas condition that was thermodynamically neutral to the intubated airway was determined.

RESULTS

Ten patients were included in the analysis (mean age 43.6 ± 19.5 years) who were ventilated for 63.9 ± 41.2 hours. The temperature recorded along the ETT showed a trend towards the average core temperature of the patient, regardless of the inspired gas temperature. A thermal steady state was created in the airway only when inspired gas was delivered to the airway at core temperature. Temperature recorded down the ETT was significantly dependent on the humidifier setting, the position of the thermocouple down the ETT and the direction of airflow in the ETT.

Inspired temperature and humidity were correlated with calculated airway workload and water loss; both were negligible when the inspired gas was at body temperature and saturated with water vapour. Airway workload and water loss varied by 1.4 kJ/h and 0.5mL/h, respectively, for each 1°C change in inspired gas temperature.

DISCUSSION

Thermodynamics in the intubated airway are different from those in the natural airway because the body's natural gas conditioning mechanism, the upper airway, is bypassed. Measurement of airway workload demonstrated that there are two components that contribute to the overall work of breathing:

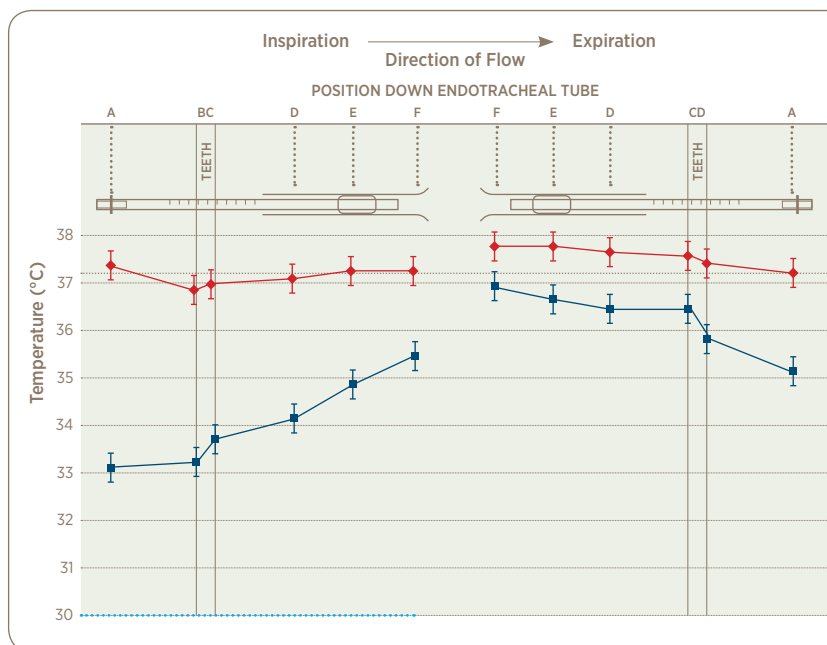
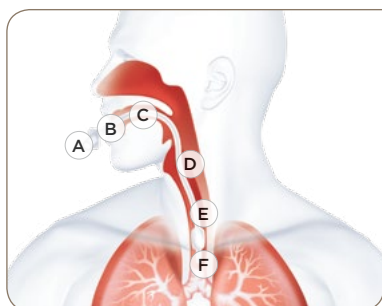
- 1) The physical work to move gas into and out of the lungs
- 2) The work required to condition inspired gases to body temperature and saturated with water vapour

Inspired gas that is at less than body temperature and not saturated with water vapour results in an overall loss of water from the airway mucosa and increases workload. Thus, delivery of gas that is not conditioned to body temperature and saturated with water vapour alters the energy balance in the airway. In turn, this change in energy balance may have a negative impact on the airway mucosa and outcome in patients undergoing mechanical ventilation whose airway is already adversely affected by disease and the presence of an ETT. (Figure 1.)

Figure 1: Changes in temperature down the intubated airway of mechanically ventilated patient during inspiration and expiration. Adapted from Ryan et al (2002).

The gases when conditioned to 37 °C, 100% RH remains around about 37 °C throughout both inhalation and exhalation.

The patient neither loses nor gains heat or moisture compared to gases conditioned to 30°C, 100% RH.



CONCLUSION:

Thermodynamics in the intubated airway are different from those in the natural airway. Airway workload and airway water loss are neutral only when inspired gas is conditioned to body temperature and saturated with water vapour. This is the only condition where heat and moisture are not lost from the airway mucosa and secretions around the end of the ETT.

KEY POINTS

- There is a correlation between the temperature and humidity of inspire gas and calculated airway workload and water loss.
- Only when inspired gas is delivered to the airway at core temperature is a thermal steady state created.
- Inspired gas that is at lower than body temperature and not fully saturated with water vapour increases workload and results in a net loss of water from the airway mucosa.
- For mechanical ventilation lasting more than a few hours, inspired gas needs to be at body temperature and fully saturated with water vapour to be thermodynamically neutral to the airway.

Wolters Kluwer Pharma Solutions

Independently produced by Wolters Kluwer Health - Adis International Ltd
World leaders in impartial pharmacoevaluation



Airway responsiveness to low inspired gas temperature in preterm neonates

AIM

This study investigated the effects of short-term exposure to inspired gas at low temperature and humidity on airway reactivity in stable preterm infants receiving mechanical ventilation.

METHOD

Eleven stable preterm infants were included in the study. Mean gestational age at delivery was 26 weeks and mean birthweight was 788g. At the time of the study, post-natal age was <28 days and mean weight was 895g. Heart and respiratory rate, pulmonary mechanics and energetics, and transpulmonary pressure, airflow and volume were measured at baseline. Patients were then exposed to room temperature and humidity (24-25°C, 45-50% humidity) for 10 minutes before being switched back to a heated humidifier, and the same parameters were recorded again at 5 and 30 minutes.

RESULTS

There were no significant changes in respiratory frequency, tidal volume and minute ventilation during room temperature and humidity (RTH) ventilation. However, compliance (small airway reactivity), conductance (large airway reactivity) and work of breathing all significantly deteriorated after exposure to RTH ventilation (see table). All of these parameters fully recovered to baseline after 30 minutes of being returned to heated humidification.

	Baseline	5 min after RTH ventilation	P value
Compliance (ml/cm H ₂ O/kg)	1.12	0.94	<0.005
Conductance (L/sec/cm H ₂ O)	0.027	0.014	<0.005
Resistive work of breathing (g-cm/kg)	12	19	<0.005

DISCUSSION

Intubated infants are often exposed to low inspired gas temperatures during routine care such as suctioning, or during emergency procedures such as manual ventilatory bag resuscitation. Airway hyper-reactivity and bronchospasm have been documented in response to inhalation of cold air in both term and pre-term infants. In this study, relatively small changes in inspired gas temperature and humidity were associated with significant alterations in pulmonary function. The greatest change occurred in large airway reactivity, which was markedly increased. It is possible that these observations explain decompensations associated with procedures such as endotracheal tube suctioning and bag to endotracheal tube ventilation. The long-term impact of repeated episodes of RTH ventilation is unclear, but compensatory responses to increase airway resistance and work of breathing during RTH ventilation episodes may contribute to ongoing problems such as fatigue and reduced weight gain.

CONCLUSION

Even short periods of ventilation with inspired gas at low temperature and humidity have an adverse effect on the neonatal airway. "These data suggest that protocols and equipment utilized in neonatal ventilatory care should be adapted to ensure that neonates who are supported by mechanical ventilation receive gas that is adequately heated and humidified."

Wolters Kluwer Pharma Solutions

Independently produced by Wolters Kluwer Health - Adis International Ltd
World leaders in impartial pharmacoevaluation



Low inspired gas temperature and respiratory complications in very low birth weight infants

AIM

This study investigated the effects of inspired gas temperature and humidity on the incidence of pneumothorax and chronic lung disease in newborn infants receiving artificial ventilation.

METHOD

Inspired gas temperature and mean airway pressure were recorded from 149 infants who received continuous ventilation during the first 96 hours of life. Humidification was provided by a Fisher & Paykel MR500, thermoregulation was controlled by a radiant warmer and ventilation was provided by a Sechrist ventilator. The infants were retrospectively divided into four groups based on incoming gas temperature ($>36.5^{\circ}\text{C}$ or $\leq 36.5^{\circ}\text{C}$) and birth weight ($\geq 1500\text{g}$ or $<1500\text{g}$). Inspired humidity was measured under the same conditions on an infant weighing $<1500\text{g}$. Pneumothorax was diagnosed by chest x-ray, and chronic lung disease by the requirement for supplementary oxygen after 28 days and an abnormal chest x-ray.

RESULTS

There was a positive linear relationship between the temperature and absolute humidity of inspired gas, ie. humidity increased with temperature. There was no significant difference in outcome at low vs high inspired gas temperature for infants weighing $\geq 1500\text{g}$ at birth. In contrast, infants with a birthweight of $<1500\text{g}$ had a significantly worse outcome at lower inspired gas temperatures (see table). There was no significant difference in pressure at high or low inspired gas temperature.

	Inspired gas temperature		P value
	34.5-36.5°C	36.6-37.6°C	
Pneumothorax (patients)	43%	13%	0.006
FiO ₂ at 29 days	37.2%	27.5%	<0.001

FiO₂ = fraction of inspired oxygen required to maintain adequate saturation..

DISCUSSION:

Inadequate humidity delivered at low inspired gas temperatures increased respiratory complications in low birth weight infants. Potential mechanisms for respiratory damage secondary to impaired mucociliary function include inflammatory changes caused by dehydration of mucus, disruption of the airway epithelium caused by cell death, and persistent airway obstruction with consequent gas trapping. The risk of airway occlusion in infants is increased compared with adults because immature airways are structurally weaker and more susceptible to injury. In addition, the narrow airway lumen in infants, especially low birth weight infants, means that they are easily obstructed. Little inhibition of mucociliary clearance would be needed to precipitate airway obstruction. Very low birth weight infants are therefore at even greater risk of impaired mucociliary function and obstruction with a small deficit in temperature and humidity.



CONCLUSION:

There is an increase in the occurrence of pneumothorax and chronic lung disease at low inspired gas temperatures (<36.5°C) in newborn infants weighing <1500g who are receiving artificial ventilation. The low inspired humidity associated with low inspired gas temperatures may predispose an infant to respiratory complications by precipitating airway occlusion. Inspired gas delivered at body temperature and fully saturated (37°C, 44 mg/L) is required to maintain optimal mucociliary function and thus prevent thickened, dehydrated mucus and airway obstruction from viscid secretions.

Wolters Kluwer Pharma Solutions

Independently produced by Wolters Kluwer Health - Adis International Ltd
World leaders in impartial pharmacoevaluation



About Optimal Humidity

Humidification is central to an Infant's Respiratory Care Continuum. Delivery of humidity appropriate for an infant's airway is essential to match the body's own natural, balanced humidification to ensure the most effective and comfortable delivery of care.



OPTIMAL HUMIDITY

37 °C, 44 mg/L, 100% Relative Humidity

During normal inspiration, the airway conditions inspired gases with heat and humidity to body temperature, 100% Relative Humidity with 44 mg/L of Absolute Humidity. The lungs rely on these optimal states to maintain the physiological balance of heat and moisture necessary for optimized airway defense and gas exchange while maintaining patient comfort.

3 Key Benefits of Humidification

1

Assisting natural defence mechanisms in the airway

2

Promoting efficient gas exchange and ventilation

3

Increasing patient comfort and tolerance to treatment



A Quick Guide to Humidity

1. Absolute Humidity

AH

A measure of the total mass of water vapor that is contained in a given volume of gas.

2. Relative Humidity

RH

A comparison of how much water vapor is contained in a gas compared with the maximum amount it can hold.

3. Temperature Affects Humidity

°C

A warm gas can hold more water vapor than a cold gas.

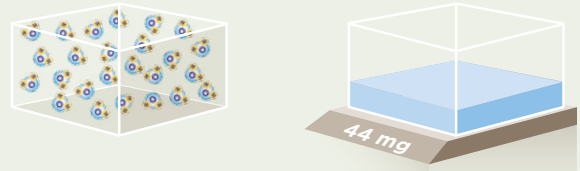
4. Size Does Matter



It is physically impossible for water vapor to transport bacteria and viruses.

01 ABSOLUTE HUMIDITY (AH)

This represents the total amount of water vapor in a given volume of gas in which it is contained. Absolute Humidity is measured as mass divided by volume of gas (mg/L).



If the water held in a liter of gas were condensed out and weighed in milligrams, the Absolute Humidity of the gas would be measured in milligrams of water per liter of gas.

02 RELATIVE HUMIDITY (RH)

This takes into account the water contained in the gas, compared with how much water it can hold before the vapor condenses out to liquid water. Relative Humidity is measured as a percentage.

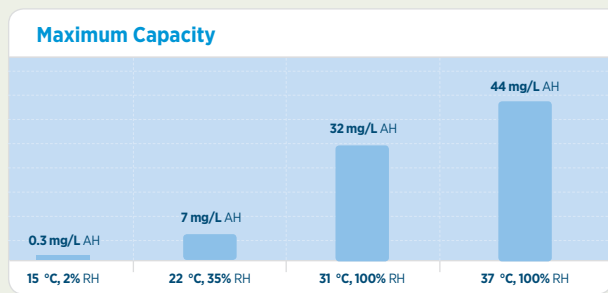


25% RH - If a liter of gas holds a maximum 44 mg of water vapor, it will be a quarter-full and contain only 11 mg of water vapor. So its Relative Humidity (RH) is 11 mg / 44 mg or 25% RH.

100% RH - If the same volume of gas holds 44 mg of water vapor, it is full or saturated with water vapor. So its Relative Humidity is 44 mg / 44 mg or 100% RH.

03 MAXIMUM CAPACITY

The quantity of water vapor that gas can hold increases with the temperature of the gas. A warm gas can hold more water vapor than a cold gas.



04 PARTICLE SIZE

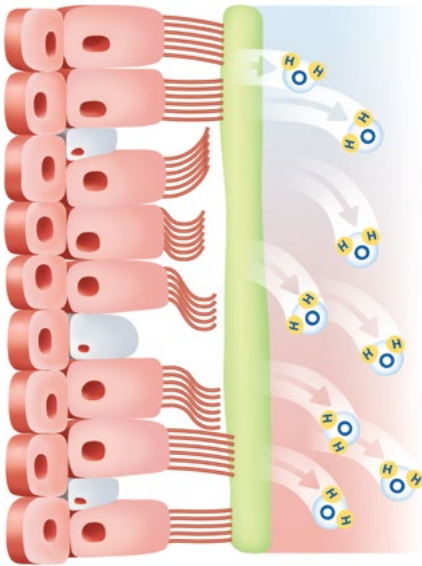
Water droplets (aerosols) are large enough that bacteria and viruses can be transported by them. Water vapor molecules are much smaller and pathogens can not attach themselves to be transported.



The Infant's Airway

An infant's respiratory system is a fragile mechanism reliant on humidity. It is necessary, therefore, to understand the physiological balance that humidity provides.

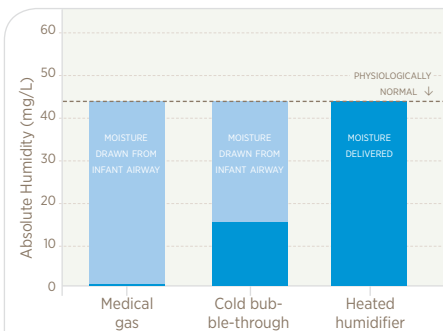
THE MUCOCILIARY TRANSPORT SYSTEM



Millions of cilia (hair-like structures) lining the epithelium of the upper and lower airways beat through an aqueous layer, moving mucus – and with it contaminants – out of the airway. The efficiency of this defense mechanism is critical in reducing the incidence of respiratory infection while optimizing gas exchange. This is reliant on the coordination and beat frequency of the cilia, and the viscosity of the mucus (which in turn is heavily influenced by the level of humidity to which the mucosa is exposed).

The airway surface contributes heat and moisture to inspired gas until it reaches 37 °C, 44 mg/L. The lower the humidity of the inspired gas, the further it needs to travel down the airway before this temperature and humidity are reached.

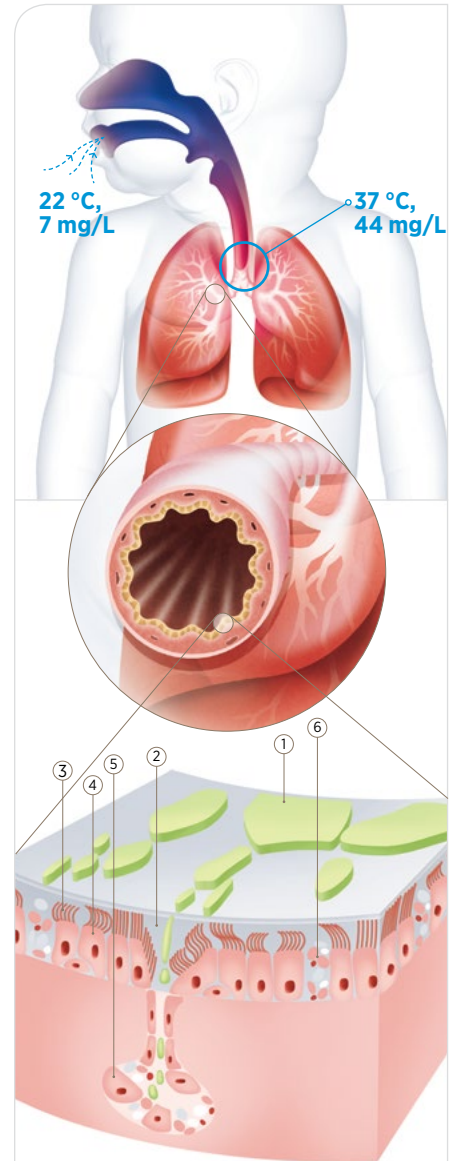
THE COMPROMISED AIRWAY OF AN INFANT



The graph above highlights the levels of humidity able to be delivered during various respiratory interventions, against what is physiologically normal (37 °C, 44 mg/L) for the lungs. The deficit must be made up by the infant's airway – requiring significant consumption of precious energy reserves.

The mucociliary transport system of an infant is inherently compromised. The cilia are often too short and uncoordinated to reach into the mucus layer effectively. Providing low-humidity gas with respiratory support can severely compromise mucociliary clearance and the underdeveloped infant even further.

Developing infants need energy for growth and development. The depletion of heat and moisture from the airway can negatively impact these limited through: Increased risk of infection, reduced respiratory mechanics, and evaporative loss.



Mucociliary Transport System

- 1 Mucus
- 2 Aqueous layer
- 3 Cilia
- 4 Epithelium cell layer
- 5 Submucosal gland
- 6 Goblet cell

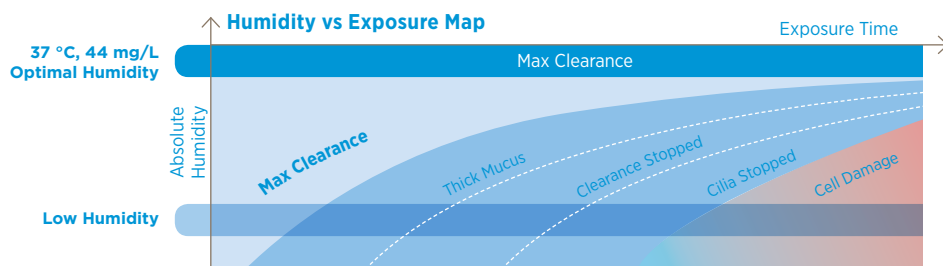
Adapted from Williams et al. (1996)¹



Invasive Ventilation

INVASIVE VENTILATION TO NURTURE LIFE

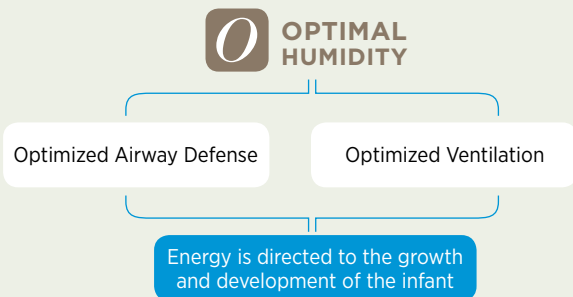
The delivery of Optimal Humidity for an intubated infant is crucial for growth and development. Inspired gases conditioned to body temperature, 37°C, and fully saturated with 44 mg/L of water vapor, will mimic the natural physiological conditioning of the airways. This optimal level of humidity will optimize the infant's airway defense, airway patency, lung function and the work of breathing.



Humidity vs exposure map, illustrating how mucosal function varies with inspired humidity over time. Adapted from Williams et al. (1996)¹

OPTIMAL OUTCOMES

Patient outcomes can be optimized with the delivery of Optimal Humidity. Optimal Humidity optimizes airway defense and ventilation. This is critical to allow the infant's limited energy reserves to be directed towards growth and development.



The delivery of Optimal Humidity provides gases that are at physiologically balanced conditions to that of the infant's airways. Optimal Humidity will:

Optimize Airway Defense

Efficient secretion clearance will increase pathogen removal and reduce sites for pathogen replication. The removal of pathogens will reduce the risk of infection.³

Optimize Ventilation

Clear Airways and Reduce Work of Breathing

Efficient secretion clearance through the delivery of Optimal Humidity will reduce the risk of endotracheal tube occlusions

and the presence of secretions blocking off airways.² A lack of drying of the airways will also reduce the infant's lung compliance, resistance to flow (RTF), and work of breathing (WOB).⁴ As shown in the graph below, just 10 minutes of room air (low humidity) delivered to the lungs via an endotracheal tube causes a significant increase in WOB.

The effect of 10 minutes of room air delivered to stable pre-term intubated infants (previously on humidification)

	Baseline	After	P Value
Compliance mL/cm H ₂ O/kg	1.12	0.94	P<0.005
RTF cm H ₂ O/L/kg	37	71	P<0.005
WOB gm-cm/kg	12	19	P<0.005

Work of Breathing	
Baseline Heated Humidification	12 ± 3
10 mins Room Air	19 ± 3

Adapted from Greenspan et al. (1991)⁴

Improve Lung Function

Lung function will improve with the delivery of Optimal Humidity. A decrease in humidity will increase the incidence of pneumothorax and the need for supplemental oxygen.⁵

Reduce Thermal Work of Breathing

If each breath is conditioned to Optimal Humidity then the infant does not need to expend energy to condition inspired gases. Energy can instead be conserved for growth and development.⁶

**100% relative humidity (RH)**

The maximum amount of water a gas can hold at a given temperature

Endotracheal tube (ETT)

A tube placed through the mouth or nose into the trachea

Gestational age

Gestation is the period of time between conception and birth.

Heated humidifier (HH)

A device which actively adds heat and water vapor to inspired gases

Intubation

The insertion of an ETT or tracheostomy tube into the trachea

Isothermic saturation boundary (ISB)

The point in the airway at which inspired gases are conditioned to body temperature and saturated with water vapor

Lung compliance

The ease with which the lung tissue can be expanded or stretched. Healthy lungs are stretchy and expand easily. A lung with low compliance is stiff and difficult to inflate. Lung compliance depends on the expansibility of both the lung tissue and thoracic cage.

Mechanical ventilation

Respiratory support method in which the act of breathing is controlled by an external mechanical device (ventilator). Can be invasive (via intubation) or non-invasive (via a face or nasal mask or cannula)

Mucociliary transport system (MTS)

The MTS lines almost the entire airway surface, from the nose down to the 15th or 16th generation of the airway. It is made up of ciliated epithelial cells, each containing 200-400 cilia, 5-8mm long, that beat rhythmically at 10-30Hz

Pharynx

The throat about 5 inches long behind the nasal cavities, mouth and larynx, connecting them to the esophagus

Pneumothorax

Abnormal presence of air between the lung and the walls of the chest, resulting in collapse of the lung

Tidal volume

Volume of air inspired or expired with each normal breath. The amount of gas delivered to a patient in one breath. Typical values are 10-15 mL for an infant.

Trachea

Cartilage air passage from the larynx to the bronchial tubes

Work of breathing (WOB)

The force required to expand the lung against its elastic properties

References

1. Williams R, Rankin N, Smith T, Galler D, Seakins P. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. *Critical care medicine*. 1996 Nov 1;24(11):1920-9
2. Pollett HF, Reid WD. Prevention of obstruction of nasopharyngeal CPAP tubes by adequate humidification of inspired gases. *Canadian Anaesthetists' Society Journal*. 1977 Sep 1;24(5):615-7.
3. van der Schans CP. Bronchial mucus transport. *Respiratory care*. 2007 Sep 1;52(9):1150-8.
4. Greenspan JS, Wolfson MR, Shaffer TH. Airway responsiveness to low inspired gas temperature in preterm neonates. *The Journal of pediatrics*. 1991 Mar 31;118(3):443-5.
5. Tarnow-Mordi WO, Reid E, Griffiths P, Wilkinson AR. Low inspired gas temperature and respiratory complications in very low birth weight infants. *The Journal of pediatrics*. 1989 Mar 31;114(3):438-42.
6. Sauer PJ, Dane HJ, Visser HK. Influence of variations in the ambient humidity on insensible water loss and thermoneutral environment of low birth weight infants. *Acta Paediatrica*. 1984 Sep 1;73(5):615-9

