## Restoring Natural Balance

The F&P Adult Respiratory Care Continuum™







Humidity is critical to human respiratory health and well-being. Our airways naturally condition inspired air to a level of temperature and humidity that enables physiological equilibrium in the airway. When this natural balance is disrupted the performance of the lung is inhibited, often resulting in difficulties delivering the necessary respiratory support and delaying recovery. Maintaining this physiological harmony is vital to a patient's outcome.

Clinical efficacy is significantly improved by emulating the balance of temperature and humidity that occurs naturally in healthy adult lungs, bridging the gap between artificial breathing systems and a normally functioning airway. For clinicians, the principal benefits of heated humidification translate to more efficient delivery of care and improved patient outcomes.

## About Humidity

Humidification is central to the F&P Adult Respiratory Care Continuum™. Our continuum delivers a level of humidity appropriate for the airway that is designed 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.



## **ESSENTIAL HUMIDITY** 31 °C, 32 mg/L, 100% Relative Humidity\*

The use of humidification with noninvasive mask therapies is essential for maintaining the natural balance of heat and moisture in the airways. The level of conditioning required is directed by the amount of humidity produced naturally in the nasopharynx when breathing through the nose.

## **3 Key Benefits of Humidification**



Assisting natural defense mechanisms in the airway



Promoting efficient gas exchange and ventilation



Increasing patient comfort and tolerance to treatment

\* Refer to A Quick Guide to Humidity on the facing page for the definition of Absolute and Relative Humidity.

## A Quick Guide to Humidity

Humidity is a measure of the water vapor that is held in a gas.

### 1. Absolute Humidity

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

### 2. Relative Humidity

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

### 3. Temperature **Affects Humidity**

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.



Č. . . . . 9° 👶 0. 00 ô, ô 6. 100% RH - If the same volume of gas

100% RH

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

WATER VAPOR VIRUS ő 20 **\***~\* •

Microns

0.017 - 0.3

Microns



0.2 - 10

Microns

1-40 Microns

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.

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The respiratory system is a highly balanced mechanism reliant on humidity. To provide therapies that maintain optimal lung function it is necessary to understand the physiological balance of humidity in the airway.

#### **TWO MAIN LUNG FUNCTIONS**

#### Gas Exchange

Air-flow to the alveoli is necessary for gas exchange. The natural heating and humidifying functions of the airway assist with maintaining clear and patent airways by promoting mucociliary clearance and reducing bronchoconstriction associated with airway cooling.

#### **Airway Defense**

Primary mechanical defense mechanisms are sneezing, coughing, gagging and the use of natural filters (nasal hairs). The second line of defense is the mucociliary transport system which traps and neutralizes inhaled contaminants (in mucus) and transports them up and out of the airway, keeping the lung free from infection-causing pathogens. This critical defense system is very sensitive to humidity.

#### HUMIDITY MAINTAINS EFFICIENT GAS EXCHANGE AND PRESERVES AIRWAY DEFENSE

As air travels down the airway, heat and moisture is drawn from the airway mucosa to the point where the gas reaches 37 °C, 44 mg/L at the carina. The majority of this conditioning is carried out in the nasopharynx. It is important for the airway mucosa to retain a balance of heat and moisture to maintain a fully functioning mucociliary transport system and an efficient line of defense. This in turn plays an important role in efficient gas exchange by maintaining clear and open airways with effective mucus clearance.

#### A HEALTHY MUCOCILIARY TRANSPORT SYSTEM



The mucociliary transport system is comprised of three layers: mucus, the aqueous layer and ciliated epithelium. These layers all contribute heat and moisture to ensure a finely tuned mucociliary transport system. Millions of cilia lining the airway (around 200 individual hair-like structures per cell) beat in the aqueous layer at up to 15 times per second. The beating cilia clear mucus and contaminants out of the airways. The clearance speed relies on the cilia beat frequency and quality of the mucus. Both are dependent on the body's ability to replenish moisture to all three layers.



#### **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)<sup>1</sup>

## Complications of Respiratory Interventions

When a patient enters the hospital environment and requires respiratory support, the natural balance of the airway can become compromised. Three key factors in particular bring about complications, as described below.

#### 1. Medical gases

Gas delivered from an artificial flow source, such as piped oxygen, is cold and extremely dry. The table below illustrates the range of temperatures and humidity levels of gas that can be delivered to patients.

	TEMPERATURE	ABSOLUTE HUMIDITY
MEDICAL GAS	15 °C	0.3 mg/L
ROOM	22 °C	7 mg/L
COLD BUBBLER	Ambient	16 mg/L <sup>2</sup>
PASSIVE HUMIDIFIER (HME)	25-30 °C	17-32 mg/L <sup>3</sup>
HEATED HUMIDIFIER	UP TO 37 °C	UP TO 44 mg/L

#### 2. A bypassed airway

An endotracheal or tracheostomy tube bypasses the upper airway where the majority of humidification would naturally occur. The tube also bypasses the airway's filtering mechanisms and compromises protective cough, gag and sneeze reflexes.

#### 3. Higher gas flows

The respiratory mechanics of patients on noninvasive therapies change with potentially higher respiratory rates, larger tidal volumes and greater inspiratory flow rates. High gas flows are also required to deliver a number of therapies along the respiratory care continuum. These factors deplete the airway mucosa of heat and moisture. The airway mucosa will continue to lose heat and moisture to the gas flow, until the gas reaches body temperature, fully saturated.





#### MUCOCILIARY DYSFUNCTION AS A RESULT OF RESPIRATORY INTERVENTIONS



Image 2 – Damaged Ciliated Epithelium

The three mechanisms indicated above can have significant adverse effects on the function of the mucociliary transport system and lead to impaired airway defense and gas exchange.

The three layers of the mucociliary transport system are compromised, which decreases or stops mucus clearance as a result of:

- The mucus layer becoming thick and tenacious
- The thickness of the aqueous layer decreasing, causing cilia to slow down or stop
- Heat loss from the epithelium cells, making cilia beat less frequently.

If the mucosa is exposed to low humidity for a long period of time, irreversible cell damage will occur.<sup>1</sup> The lungs may already be compromised by pre-existing mucociliary dysfunction (e.g. due to age, smoking, chronic obstructive pulmonary disease (COPD), etc.). To avoid further complications, provision of physiological levels of humidity becomes even more important for patients with these conditions.

Image 1 – Braga and Piatti. (1992)<sup>4</sup> Image 2 – (Photograph) Courtesy of Hulbert W.C, University of Alberta Pulmonary Defense Group

*Humidification allows the airway to maintain a natural balance of heat and moisture – optimizing gas exchange, lung defense and patient comfort.* 

## Restoring Natural Balance



## **F&P ADULT RESPIRATORY CARE CONTINUUM™**

Fisher & Paykel Healthcare is committed to advancing our capabilities as a world leader in humidified therapy systems with a comprehensive family of solutions that restore natural balance. At every point of the F&P Healthcare Adult Respiratory Care Continuum<sup>™</sup>, high-performance respiratory systems are designed to deliver optimal patient and clinician outcomes.



**OPTIFLOW<sup>™</sup>** Nasal High Flow

Respiratory support via nasal cannula





### **INVASIVE VENTILATION**

Optimal Humidity delivered to optimize airway defense and ventilation



## **F&P ADULT RESPIRATORY CARE CONTINUUM™**

# Therapy Solutions Overview

#### **Restoring Natural Balance**

By delivering optimal humidification along the Respiratory Care Continuum, Fisher & Paykel Healthcare's therapy solutions emulate the natural physiological balance in healthy human lungs. The result - optimal care and outcomes that extend the boundaries of traditional adult respiratory care.

## Optiflow<sup>™</sup> Nasal High Flow



### Respiratory support via cannula

Optiflow<sup>™</sup> Nasal High Flow (NHF) is a new, versatile method of respiratory support, delivering high flows of warmed and humidified respiratory gases through a unique Optiflow<sup>™</sup> nasal cannula.

Nasal cannulas generally promote greater patient comfort and compliance than that provided by face masks, meaning that patients can continue to eat, drink, talk and sleep easily without therapy interruption. With Optiflow<sup>™</sup> NHF, you can independently titrate flow and FiO<sub>2</sub> according to your patient's needs. The mechanisms of action differ from those of conventional therapies, as do the resulting physiological effects and clinical outcomes.



#### PATIENT NEEDS AND OPTIMAL OUTCOMES

The combination of Optimal Humidity with an Optiflow<sup>™</sup> nasal cannula allows a greater level of respiratory support than does a traditional nasal cannula, delivering a range of flows effectively and comfortably. Contributing to this is the delivery of four key benefits:

#### 1. Reduction of dead space

With the delivery of high flows directly into the nares, a flushing effect occurs in the pharynx.<sup>8 9</sup> The anatomical dead space of the upper airway is flushed by the high incoming gas flows. This creates a reservoir of fresh gas available for each and every breath, minimizing re-breathing of carbon dioxide (CO<sub>2</sub>).<sup>9</sup>

#### 2. Dynamic positive airway pressure

Mean airway pressure during the respiratory cycle has been shown to be elevated with the delivery of Optiflow™ NHF (as indicated by the graph below right).<sup>10</sup>

The degree of pressure is likely to be dependent on a number of variables, including flow rate, geometry of the upper airway, breathing method (through the nose or mouth) and size of the cannula relative to the nare.<sup>6 pm</sup>

#### 3. Supplemental oxygen

With Optiflow<sup>™</sup>, the aim is to meet or exceed the patient's normal inspiratory demand, creating minimal air dilution, as indicated by images 1 and 2 opposite.<sup>8 12</sup> Optiflow<sup>™</sup> can more accurately deliver prescribed oxygen concentrations in a range of flows, providing both versatility and continuity of care as patients wean or their condition becomes more acute.<sup>12 13</sup> This greater flexibility eliminates the need to switch between oxygen therapy

#### delivery systems.

#### 4. Airway hydration

Optimal Humidity emulates the balance of temperature and humidity that occurs in healthy lungs, maintaining mucociliary clearance.<sup>14 15</sup> This can be particularly important for patients with secretion problems such as those with chronic obstructive pulmonary disease (COPD).<sup>15 16</sup> By achieving Optimal Humidity, drying of the airway is reduced, which maintains the function of the mucociliary transport system, clearing secretions more effectively and reducing the risk of respiratory infection "Optimal Humidity emulates the balance of temperature and humidity that occurs in healthy lungs, maintaining mucociliary clearance." <sup>14 15</sup>



IMAGE 1: OPTIFLOW™ NHF



**IMAGE 2: MASK OXYGEN THERAPY** 



Pressure waveform of one subject with 35 L/min comparing face mask with Optiflow™, adapted from Parke et al. (2007)<sup>10</sup>

#### **OPTIFLOW™ AND HUMIDITY THERAPY**

In key patient groups, such as those with COPD or bronchiectasis, maintaining clear, unobstructed airways can be difficult due to the volume and thickness of secretions that are generated within the lungs.

A compromised mucociliary clearance system further impedes the patient's ability to clear secretions. The velocity of mucus transport in a COPD patient may be less than 1 mm per minute, compared to 10 mm per minute in a healthy adult.<sup>17</sup>

Video microscopy of ovine tissue has indicated that delivery of heated and humidified air at body core temperature, and saturated, improves mucus transport velocity in the trachea. This effect was also investigated by Hasani et al.,<sup>15</sup> who found that in bronchiectatic patients treated with humidification therapy for only three hours per day, mucociliary clearance increased by 15%. The improvement in mucociliary clearance can be seen in the graph below. Humidity Therapy can provide significant benefit to patients in both the hospital and home environments.





### "Freedom to breathe"

Mean tracheobronchial aerosol retention graph showing the clearance of inhaled labeled particles (radioaerosols) from the lung. Improvement in clearance is indicated by the smaller area under the curve post treatment.

Adapted from Hasani et al. (2008)<sup>15</sup>

Differentiated mechanisms	Physiological outcomes	Clinical outcomes	Potential benefits
Respiratory support	Improves ventilation and gas exchange	Reduces escalation of care	Reduced length
	Reduces respiratory rate	Reduces	of stay
Airway hydration	Reduces carbon dioxide	mortality rate	Reduced
Patient	Increases tidal volume	patient comfort and compliance	cost of care
comfort	Increases end-expiratory lung volume	Improves	Improved
Supplemental oxygen (when required)	Improves mucus clearance	Reduces	patient care and outcomes
	Improves oxygenation	exacerbation days	

## Noninvasive Ventilation



## Essential Humidity for a successful noninvasive ventilation strategy

Noninvasive positive pressure ventilation therapy (NPPV or NIV) is respiratory support without the use of an endotracheal tube, such as during treatment with continuous positive airway pressure (CPAP) or bi-level ventilation.<sup>18</sup>

NIV is used to support patients with a range of respiratory diseases without the complications associated with endotracheal intubation. NIV promotes gas exchange in the lungs by providing a bulk flow of fresh gas to the alveoli on each inspiration. The use of inspiratory and expiratory positive pressure helps to reduce the work of breathing for the patient.<sup>5</sup>

#### **OPTIMAL OUTCOMES**

#### **Maximize Patient Tolerance to Therapy**

Complications occur in up to 70% of patients receiving noninvasive ventilation.<sup>19</sup> Many of these complications are related to a lack of humidity, leading to patient discomfort and intolerance to the therapy. Mask disturbance or removal will result in compromised ventilation, increasing the risk of intubation. Humidified therapy maximizes patient tolerance, improving the overall success rates of NIV. <sup>20 21 22 23</sup>



#### PATIENT NEEDS

It is often assumed that a patient being ventilated noninvasively can adequately humidify their own airway. However, there are several factors associated with NIV that can compromise the patient's ability to heat and humidify inspired gases, overwhelming the patient's airway conditioning system. These include:

#### **Fluid Depletion**

The patient being treated by NIV is often fluid depleted due to respiratory distress

and presents pre-existing secretion removal problems caused by an underlying respiratory disorder, making them more susceptible to airway drying.<sup>19 20</sup>

#### Oral Breathing to Reduce the Work of Breathing

Patients receiving NIV tend to breathe through their mouth as this requires less work to breathe. As a consequence, gases reaching the airway can be 4 °C cooler and, more importantly, contain 11 mg/L less moisture than if the air had been inhaled through the nose.<sup>19 24</sup>

#### **Increased Ventilation Rate**

NIV patients are typically short of breath and increase their ventilation rate by breathing faster and deeper as they attempt to move more oxygen into their lungs. This increases the volume of gas passing through the respiratory system, increasing the amount of moisture lost from the airways.<sup>19</sup>

## "Humidification of the upper airway is important to improve comfort and tolerance." <sup>5</sup>



#### **Minimize Airway Drying**

Achieving Essential Humidity with NIV can prevent drying of the airway, avoiding the inflammatory response caused to the mucosa as a result.<sup>20 28</sup> Conditioning of the gas can also minimize airway constriction, reducing the work of breathing.<sup>21 23 29</sup> This helps to maintain effective delivery of pressure to the lungs.<sup>21 23</sup>

#### Improve Secretion Clearance

Airway dehydration makes mucus secretions viscous and sticky, which causes them to build up in the airway, reducing its diameter and increasing resistance to flow.<sup>26 29 30</sup> As a consequence, the respiratory muscles must work harder, increasing the work of breathing. Achieving Essential Humidity restores fluid levels in the mucociliary transport system, improving secretion clearance and maintaining the work of breathing at normal levels.<sup>28</sup>



Adapted from Tuggey et al. (2007)<sup>21</sup>



BENEFITS OF NONINVASIVE VENTILATION WITH ESSENTIAL HUMIDITY			
PATIENT	CLINICIAN		
Reduced dry mouth, cracked lips, nosebleeds	Fewer breaks in ventilation		
Minimized airway drying, inflammation <sup>28</sup>	Less time required refitting face masks		
Reduced congestion and bronchoconstriction <sup>212329</sup>	Less oral care for dry mouth		
Improved secretion clearance <sup>26</sup>	More comfortable patients <sup>5 21</sup>		
Improved work of breathing <sup>23</sup>	Increased NIV therapy tolerance <sup>5 22</sup>		
Improved ventilation <sup>21 23 29</sup>	Increased confidence in noninvasive therapy		

## Invasive Ventilation



## Optimal Humidity delivered to optimize airway defense and ventilation

## The delivery of Optimal Humidity for an intubated patient is crucial for the best outcome.

Gases conditioned to body temperature, 37 °C, and fully saturated with 44 mg/L of water vapor, will optimize mucociliary clearance. As a result, the patient's airway defense and ventilation will emulate the natural physiological function of the airway. The lungs rely on these optimal states to maintain the physiological balance of heat and moisture necessary for optimized airway defense and gas exchange.



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



"...only inspired gas that is conditioned to core temperature and that has 100% Relative Humidity allows optimal mucociliary transport velocity; conversely, any greater or lesser condition reduces the transport rate."<sup>1</sup>

#### PATIENT NEEDS

#### **Airway Defense**

An endotracheal or tracheostomy tube not only bypasses the body's natural humidification processes but also inhibits mechanical clearance such as cough, gag, sneeze and particle filtration. This leaves the mucociliary transport system as the airway's only remaining mechanical defense mechanism.

#### Ventilation

Clear and unobstructed airways are necessary to ventilate the patient effectively.

Although not always visible, secretions that are thick, tenacious, bloody or copious can block airways and endotracheal/ tracheostomy tubes. Mobilizing these secretions to prevent and reduce airway blockage is of high priority.<sup>30</sup>

For effective ventilation it is vital to minimize the patient's instrumental dead space and resistance to flow in the breathing system. It is generally recognized that patients with acute respiratory distress syndrome (ARDS) require lower tidal volume ventilation strategies (enabled by a decreased amount of dead space) for improved outcomes.<sup>31</sup> Also, patients who are potentially difficult to wean (e.g. patients with COPD) will benefit from this reduction in dead space, resulting in less resistance to flow and work of breathing.<sup>32</sup> Heated humidification systems provide the opportunity to reduce dead space and resistance to flow.

#### **OPTIMAL OUTCOMES**

#### Optimal Humidity restores mucociliary clearance leading to:

### • **Optimized Airway Defense**<sup>33</sup> Efficient secretion clearance will increase pathogen removal and reduce sites for pathogen replication.

#### • Optimized Ventilation

Efficient secretion clearance and use of a heated humidifier will increase airway patency,<sup>17</sup> reduce the work of breathing<sup>32</sup> and enable the delivery of lower tidal volumes.<sup>31</sup>





pathogen clearance Reduces pathogen replication sites

Optimized airway defense



d-up blockage

Optimized ventilation

#### HEATED HUMIDIFICATION SYSTEM

Allows for Reduces the work of ventilation strategies

Optimized ventilation & weaning

\*Compared to passive humidification



#### BENEFITS OF INVASIVE VENTILATION WITH OPTIMAL HUMIDITY

PATIENT	CLINICIAN
Airway Defense	Best level of patient care can be provided
Increased airway defense, reducing risk of respiratory infection <sup>33</sup>	Suctioning can become more effective
Ventilation	Aerosol and drug delivery may be reduced
Increased patency of endotracheal tubes via decreased secretion build-up <sup>24</sup>	May reduce institutional cost through effective patient care
Reduction in incidence of small airway blockage <sup>1</sup>	
Ability to deliver lower tidal volumes (e.g. ARDS) <sup>31</sup>	
Reduced respiratory effort <sup>32</sup>	
More effective weaning <sup>32</sup>	

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