Adult Invasive Ventilation

Clinical Paper Summaries

Fisher & Paykel HEALTHCARE

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PubMed

R Williams, N Rankin, T Smith, D Galler, P Seakins
Critical Care Medicine 1996; 24(11): 1920-1929

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 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 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 deficity, and the duration of exposure to these deficits.

DEFINITIONS:

100% relative humidity (RH)	The maximum amount of water a gas can hold at a given temperature
Isothermic saturation boundary (ISB)	The point in the airway at which inspired gases are conditioned to body temperature and saturated with water vapour
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

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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.

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.

DEFINITIONS:

Endotracheal tube (ETT)	A tube placed through the mouth or nose into the trachea
Heated humidifier (HH)	A device which actively adds heat and water vapour to inspired gases
Mechanical ventilation (MV)	Method to mechanically assist or replace spontaneous breathing when patients cannot do so on their own
Work of breathing	The force required to expand the lung against its elastic properties

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L Lorente, M Lecouna, A Jiménez, ML Mora, A Sierra
Critical Care 2006; 10(4): R116

Ventilator-associated pneumonia using a heated humidifier or a heat and moisture exchanger – a randomized controlled trial

AIM:
This study compared the incidence of ventilator-associated pneumonia (VAP) in intubated patients receiving humidification with a heat and moisture exchanger (HME) or heated humidifier (HH).

METHOD:
Patients from the intensive care unit (ICU) at a hospital in Tenerife, Spain, from Jan-Dec 2005 who were expected to require mechanical ventilation (MV) for >5 days, were randomised to have humidity delivered by either an HME (Edith Flex®; Datex-Ohmeda) or an HH (MR 850®; Fisher & Paykel Healthcare Ltd or Aerodyne 2000®; Tyco Healthcare/Nellcor). The HHs were servo-controlled with wire-heated circuits without water traps and were set to deliver a temperature of 37°C and 100% relative humidity to the proximal airway (containing ≈44mg H_2O/L gas as per manufacturer's recommendations). The HME devices were changed at 48-hour intervals.

VAP was diagnosed after 48 hours of MV in patients with: new onset bronchial purulent sputum; body temperature >38°C or <35.5°C; white blood cell count >10,000/mm^3 or <4,000/mm^3; new or progressive infiltrates on chest radiography; and a significant tracheal aspirate culture of respiratory secretions (>106cfu/mL). Tracheal aspirate samples were obtained on endotracheal intubation, then twice weekly, and again on extubation. VAP was classified as endogenous or exogenous according to analysis of throat swabs (taken on admission to the ICU, then twice weekly, and again on discharge from the ICU).

RESULTS:
The study included 120 patients (39% female; mean age 55 years); data from 16 patients who received MV for <5 days were excluded from the analysis. There was a significantly lower incidence of VAP in patients receiving humidification with HHs versus HMEs. The rates of VAP, adjusted for the Acute Physiology and Chronic Health Evaluation II score, are presented below.

	HME (n = 53)	HH (n = 51)	Hazard ratio (95% confidence interval)	P-value
VAP patients (%):				
Overall VAP	21 (39%)	8 (15%)[*]	16.20 (4.54-58.04)	<0.001
VAP caused by Gram-positive cocci	8 (15%)	3 (5%)	5.44 (1.08-27.31)	0.04
VAP caused by Gram-negative bacilli	13 (24%)	5 (9%)	23.54 (2.98-186.07)	0.003
Primary endogenous VAP	8 (15%)	1 (1%)	8.56 (1.07-68.70)	0.04
Secondary endogenous VAP	12 (22%)	6 (11%)	12.45 (2.65-58.38)	0.001
Median time free of VAP (days)	42	20[#]		
Duration of MV (days)	19.47	20.82		

[*] P = 0.006 vs HME; [#]P <0.001 vs HME

DISCUSSION:
These results contrast with those of previous meta-analyses which suggest that a lower incidence of VAP when using HMEs for humidity delivery may be attributable in part to reduced contaminated condensate in the HME circuit. This study used servo-controlled HHs to reduce the risk of contaminated condensate entering the airway. Also, the duration of MV in this study was relatively long (≈20 days) compared with previous studies (4-14 days), and the optimal levels of humidity (44mg H_2O/L) delivered to the airways may have facilitated maximal mucociliary clearance. In contrast, HMEs do not maintain optimal humidification and mucociliary transport for more then 24 - 48 hours of MV. Limitations of this study include the non-invasive diagnostic procedure for VAP, and the lack of direct and indirect assessments of gas heating and humidification in patients.

CONCLUSION:
The incidence of VAP in patients undergoing MV for >5 days is significantly lower when inspired gases are humidified using an HH rather than an HME.

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F Konrad, T Schreiber, D Brecht-Kraus, M Georgieff
Chest 1994; 105(1): 237-241

Mucociliary transport in ICU patients

AIM:
To investigate the velocity of bronchial mucus transport in ventilated intensive care unit (ICU) patients and to study the possible role of impaired mucus transport in the development of retention of secretion and pneumonia.

METHOD:
In this prospective study, the bronchial mucus transport velocity (BTV) of ventilated, surgical ICU patients who were expected to be orally intubated for at least four days was investigated. The effect of impaired BTV on pulmonary complications was also assessed.

Mechanical ventilation was volume controlled (Siemens Servo C): the fraction of inspired oxygen (FiO_2), positive end-expiratory pressure (PEEP) and inspiratory-expiratory ratio were adjusted depending on the extent of respiratory failure. BTV was determined within the first three days after initiation of mechanical ventilation and all patients were examined on each of the four days following BTV determination. BTV was measured in the right and left primary bronchus using technetium 99m-labelled macro-aggregated albumin (^{99m}Tc-MAA) with a diameter of 10–40 μm (Maascing, Medgenix, Brussels, Belgium). A radiolabelled bolus of ^{99m}Tc-MAA was deposited into the mucosa of the distal bronchus and a dynamic data acquisition tool with a scintillation camera was used. Pulmonary complications were defined as retention of secretion with requirement for bronchoscopic suctioning, or development of pulmonary infection.

RESULTS:
Thirty-two orally intubated patients (11 female, 21 male; age 18-95 years) were enrolled in this study. The median BTV was 0.8 mm/min in the right bronchus and 1.4 mm/min in the left bronchus. In 9 patients (28.1%), both radioactive markers remained in the application site and reassessment after 1 hour confirmed that no bronchial transport had occurred. Fourteen patients experienced 19 pulmonary complications (10 cases of secretion retention and 9 cases of pneumonia). BTV was significantly lower in patients who developed pulmonary complications than in those who did not develop pulmonary complications ($P<0.01$). The median BTV in patients who developed pulmonary complications was 0 (0–3.0) mm/min (right bronchus) and 0 (0–6.5) mm/min (left bronchus). In comparison, corresponding values in those without pulmonary complications were 4.7 (0–11.7) mm/min and 3.5 (0–10.5) mm/min (both $P<0.01$ for comparison between those with and without pulmonary complications). One or more pulmonary complications developed in eight of the nine patients without measurable mucous transport whereas only six of the other 23 patients had a pulmonary complication ($P<0.01$).

DISCUSSION:
The average tracheal transport velocity in humans is approximately 10 mm/min, assessed using bronchofiberscopic methods. In anaesthetised, intubated, healthy non-smoking patients a median BTV of 9 mm/min has been reported. In this study, ICU patients receiving expected long-term mechanical ventilation had a median BTV of about 1 mm/min. Possible explanations for this slow underlying BTV include the fact that the patient population was a heterogeneous caseload from a general surgical ICU and that 50% of patients were smokers. Other factors that are known to affect BTV include possible drug effects, ventilation with high oxygen concentrations, activation of inflammatory mediator systems, bacterial colonisation, suction-induced lesions and respiratory virus infections. None of these were assessed in this study. The results of this study do show that reduced BTV was associated with the development of secretion retention and/or nosocomial pneumonia.

This highlights the issue that mucus is important for microbial persistence and for the multiplication of pathogenic microorganisms.

CONCLUSION:
This study demonstrated that mechanically ventilated patients in the ICU frequently have impaired mucus transport and this can be associated with the development of pulmonary complications such as retention of secretion and nosocomial pneumonia.

KEY POINTS:
- Mechanically ventilated patients in the ICU have significantly reduced mucus transport.
- Reduced mucus transport is associated with retention of secretion and an increased incidence of nosocomial pneumonia.

DEFINITIONS:

Bronchial transport velocity (BTV)	The speed at which mucus travels along the bronchus
Fraction of inspired oxygen (FiO_2)	The fraction of oxygen in inspired gas
Intensive care unit (ICU)	A hospital facility providing intensive nursing and medical care for critically ill patients
Mechanical ventilation (MV)	The use of an invasive artificial airway to mechanically assist or replace spontaneous breathing, when patients cannot do so on their own
Nosocomial pneumonia	Pneumonia acquired in the hospital inpatient environment, not resulting from the reasons for which the patient was admitted
Positive end-expiratory pressure (PEEP)	The amount of pressure above atmospheric pressure present in the airway at the end of the expiratory cycle during mechanical ventilation

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DHT Scott, S Fraser, P Willson, GB Drummond, JK Baillie
Anaesthesia 2010; 65: 670-673

Passage of pathogenic microorganisms through breathing system filters used in anaesthesia and intensive care

AIM:
To determine the ability of pathogenic organisms to pass through bacterial filters.

METHOD:
Six readily-available breathing filters were assessed; three were hydrophobic pleated filters designed for use as heat and moisture exchanger (HME) filters [Dar Hygrostar™, Pall BB 22-15, Intersurgical Hydro-guard®], one was a hydrophilic unpleated HME filter [Intersurgical Clear-therm®] and two were simple filters [Intersurgical Filta-guard®, Intersurgical Clear-guard®]. Sterile saline or suspensions of Candida albicans (12 μm diameter) or coagulase-negative staphylococcus (1 μm diameter) were infused at 999 mL/h through each filter; two filters of each type were used and all were oriented vertically. Filters started completely dry and the volume infused before fluid started to flow was recorded. The first drops of fluid that passed through each filter were collected into a sterile container for culture. In a separate experiment, a pressure transducer was used to determine the pressure at which sterile saline first started to flow from the open end of the filter.

RESULTS:
Candida albicans and coagulase-negative staphylococcus suspensions passed through all filters tested. The bacterial cultures taken from filtered solutions were largely indistinguishable from cultures of unfiltered test suspensions; control cultures of sterile saline showed no micro-organism growth.

Passage of fluid through filters

	Volume infused before fluid passed through (mL)	Pressure at which passage first occurred (cm H_2O)
Median	35	20
Interquartile range	26-62	0-48
Range	20-80	0-138

DISCUSSION:
The risk of hospital-acquired infection is increased by tracheal intubation and mechanical ventilation. Bacterial filters are used to prevent contamination of the ventilator breathing system. However, the international standard for testing breathing system filters does not take into account what happens when filters get wet with condensed water and airway secretions, which often happens in clinical practice. Data from this study indicate that viable micro-organisms, including large yeasts, can pass through breathing system filters under clinical conditions, even at very low pressure. It remains to be established to what extent this occurs in clinical practice and further studies are required to determine whether use of breathing system filters as the only system of infection control is associated with a risk of cross-contamination during anaesthesia or in the intensive care setting.

KEY POINTS:
- Bacterial filters do not prevent passage of micro-organisms when wet.
- Under clinical conditions where bacterial filters may become wet with condensed water and airway secretions the risk of micro-organism passage through the filter is high.

DEFINITIONS:

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

A Doyle, M Joshi, P Frank, T Craven, P Moondi, P Young
Journal of Critical Care 2011; 26(6): 637.e1-637.e4

A change in humidification system can eliminate endotracheal tube occlusion

AIM:
To compare the incidence of endotracheal tube (ETT) occlusion during use of a hydrophobic heat and moisture exchanger (HME) compared with a heated humidifier (HH).

METHOD:
This single-centre prospective observational study was conducted during the switch from providing humidification using an HME (Thermovent Hepa; Portex) to the introduction of a RT dual-heated wire circuit with MR290 autofeed humidification chamber HH system (Fisher & Paykel Healthcare). The switch was prompted by hospital critical incident reporting system data indicating a higher than expected incidence of ETT occlusion requiring emergency reintubation during the exclusive use of HMEs in 2007.

All intensive care unit (ICU) patients requiring intubation over a 16-month period during the introduction of the HH system were included in the analysis. Assignment to humidification system was based on the expected duration of intubation; patients anticipated to require intubation for >24 hours were assigned to the HH group (temperature at y-piece set to 37ºC) while those who were thought to require intubation for <24 hours had humidity delivery via an HME. ETT occlusion was defined as an inability to ventilate the patient which resolved after an emergency change of the ETT.

RESULTS:
246 patients required intubation during the study period; humidification delivery was via HME in 158 patients and via HH in 88 patients. Overall, ETT tube occlusion occurred exclusively in the HME group with 9 occlusions reported, as detailed in the table below. ETT occlusion was treated with emergency tube change in all patients and two patients also underwent bronchoscopy; one patient had respiratory arrest and died. In the 18-month period after the end of the study, during which time humidification was exclusively provided using a HH system no further episodes of ETT occlusion were reported.

	HME (n=158)	HH (n=88)
ETT occlusion, n (%)	9 (5.7)[a]	0 (0)
Mean time to ETT occlusion, days	2.3	-

[a] P=0.02

DISCUSSION:
The advantages of HMEs for humidification delivery include low cost, ease of use and the option to include a bacterial filter. However, the absolute humidity of delivered gases is 25-30 mg/L and studies have shown a greater reduction in internal ETT diameter during the use of an HME versus a HH, as well as a potential increase in the incidence of ETT occlusion. A HH delivers gas at 35-45 mg/L (100% relative humidity) and the use of a heated wire circuit largely eliminates the occurrence of condensation in the breathing circuit.

Although the optimum humidification system for ICU patients remains unclear, the results of this study indicate that when intubation is expected to be required for >24 hours, a HH may be preferable in terms of minimizing the risk of ETT occlusion. These findings require confirmation in a larger, randomized, multicentre trial.

CONCLUSION:
Use of a hydrophobic HME for humidification in intubated ICU patients may be potentially harmful because of the risk of ETT occlusion. The risk of ETT occlusion is eliminated when a HH is used. HME use is still appropriate for ventilation <24 hours and during anaesthesia.

KEY POINTS:
- The rate of ETT occlusion is significantly lower in ICU patients receiving humidification via HH versus HME.
- Switching to a HH system can eliminate ETT occlusion in ICU patients.

DEFINITIONS:

Endotracheal tube (ETT)	A tube placed through the mouth or nose into the trachea to maintain an unobstructed airway
Heated humidifier (HH)	A device which actively adds heat and water vapour to inspired gases
Heat and moisture exchanger (HME)	A passive humidification device that is designed to collect and hold some of the heat and moisture from the patient's exhaled breath, and to return them to the inspired gas mixture during inspiration
Intensive care unit (ICU)	A hospital facility providing intensive nursing and medical care for critically ill patients

I Morán, J Bellapart, A Vari, J Mancebo
Intensive Care Medicine 2006; 32: 524-531

Heat and moisture exchangers and heated humidifiers in acute lung injury/acute respiratory distress syndrome patients. Effects on respiratory mechanics and gas exchange

AIM:
To investigate the effect of reducing instrumental dead space on alveolar distension, respiratory system compliance and end-inspiratory plateau pressure while keeping the partial pressure of carbon dioxide in arterial blood ($PaCO_2$) constant in mechanically ventilated patients with acute lung injury or acute respiratory distress syndrome (ALI/ARDS).

METHOD:
The study included 17 patients (mean 62 years) who had ALI/ARDS diagnosed according to the American-European Consensus Conference criteria. Mechanical ventilation was volume assisted with a constant flow, low tidal volume (Vt) and moderate positive end-expiratory pressure (PEEP) to keep plateau airway pressure (Pplat) ≤ 35 cmH_2O. In basal conditions (phase 1), a heat and moisture exchanger (HME; Edit Flex; Datex Engstrom) was placed distally to the Y-piece of the circuit. Patients were then switched to humidity delivery using a heated humidifier (HH; MR850 + MR290; Fisher & Paykel)(phase 2). In both phase 1 and phase 2 data were collected after 45 minutes of stable mechanical ventilation. Next, use of a HH was continued but tidal volume was decreased by 20-30mL every 30 minutes until a $PaCO_2$ equal to that under basal conditions was reached (phase 3).

RESULTS:
Respiratory results are reported in the table. There were no significant differences between treatment groups in total PEEP, respiratory rate, partial pressure of oxygen in arterial blood and the fraction of inspired oxygen.

	HME (phase 1)	HH (phase 2)	HH with low Vt (phase 3)
Peak airway pressure (cmH_2O)	36	34[a]	29[ab]
Pplat (cmH_2O)	25	25	21[ab]
Vt (mL)	521	521	440[ab]
Physiologic dead space (Vd_{phys}; mL)	352	310[a]	269[ab]
Vd/Vt	0.69	0.60[a]	0.62[ab]
Respiratory system compliance (mL/cmH_2O)	35	35	42[ab]
Arterial pH	7.34	7.39[a]	7.33[b]
$PaCO_2$ (mmHg)	46	40[a]	45[b]
Compressible volume (Vc; mL)	53	52	43[ab]
Vt taking into account Vc (mL)	468	469	397[ab]
Vd_{phys} taking into account Vc (mL)	316	279[a]	243[ab]
Respiratory system compliance taking into account Vc (mL/cmH_2O)	32	32	38[cd]

[a] P ≤ 0.001 vs HME; [b] P ≤ 0.001 vs HH; [c] P = 0.002 vs HME; [d] P = 0.002 vs HH.

DISCUSSION:
Reduction of instrumental dead space in ALI/ARDS patients undergoing mechanical ventilation by switching from an HME to a HH is associated with a significant decrease in $PaCO_2$ levels. Under hypercapnic conditions, switching to a HH allowed the use of lower tidal volumes, which in turn significantly reduced physiological dead space and plateau airway pressure. Furthermore, the reduction in tidal volume was associated with significant improvements in respiratory system compliance.

CONCLUSION:
Reducing artificial airway dead space is a useful strategy to improve respiratory mechanics and gas exchange in mechanically ventilated patients with ALI/ARDS.

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C Girault, L Breton, J-C Richard, F Tamion, P Vandelet, J Aboab, J Leroy, G Bonmarchand
Critical Care Medicine 2003; 31(5): 1306-1311

Mechanical effects of airway humidification devices in difficult to wean patients

AIM:
To compare the effects of a heat and moisture exchanger (HME) and a heated humidifier (HH) on diaphragmatic muscle activity, breathing pattern, gas exchange and respiratory comfort during weaning in patients with chronic respiratory failure receiving mechanical ventilation (MV) with pressure support ventilation (PSV).

METHOD:
This prospective, randomized, controlled crossover trial enrolled 15 consecutive patients in a single French medical intensive care unit. Patients had chronic respiratory failure, were considered difficult to wean and had failed a spontaneous breathing weaning trial of ≤ 2 hours within the 24 hours prior to the study. Ventilation was provided by an NPB 840 ventilator (Mallinckrodt). The HH (MR730; Fisher & Paykel Healthcare) and HME (Hygrobac; DAR) devices were studied for ≥ 20 minutes during PSV at two different levels: 7 and 15cm H_2O. The order of use of the different devices and PSV levels was randomized for each patient, and separated by 20-minute periods of MV in the volume assist-controlled mode. Patients were not explicitly informed of changes in the device or level of PSV used. Respiratory variables were measured at the end of each PSV sequence. Respiratory comfort was assessed using a visual analogue scale (VAS) from 0 (very uncomfortable) to 100 (very comfortable).

RESULTS:
Eleven patients were included in the analysis; three were withdrawn due to intolerance of the HME and one because they refused to continue in the study. Values for respiratory parameters that showed significant differences between treatment groups are reported in the table. At both levels of PSV, VAS scores for respiratory comfort were significantly higher for the HH compared with the HME (p‹0.01). In addition, VAS score was significantly higher with the HH at PSV 7cm H_2O compared with the HME at PSV 15cm H_2O (p‹0.01).

	PSV 7cm H_2O		PSV 15cm H_2O	
	HME	**HH**	**HME**	**HH**
Wi (J/L)	1.71	1.35[a]	1.40	0.93[a]
Wi (J/min)	20.19	14.44[b]	16.50	9.86[a]
PTPdi (cm H_2O•sec/min)	12.40	9.20b	9.16	7.48b
ΔPdi (cm H_2O)	19.45	14.18[a]	13.64	9.86[a]
ΔPes (cm H_2O)	22.38	18.57[b]	19.88	19.88[a]
$\dot{V}_E$ (L/min)	13.4	12.4[bc]	13.9	12.9[b]
Paw (cm H_2O)	1.5	2.8[bc]	7.2	8.4[b]
PEEPi (cm H_2O)	6.5	4.5[bd]	5.6	4.9
pH	7.30	7.35[bd]	7.29	7.38[a]
$PaCO_2$ (kPa)	8.5	7.0[ad]	8.4	6.5[a]
$FetCO_2$ (%)	6.9	5.7[ad]	6.5	5.3[a]

Wi = total inspiratory work of breathing; PTPdi = pressure time product; ΔPdi = transdiaphragmatic pressure variations; ΔPes = oesophageal pressure variations; $\dot{V}_E$ = minute ventilation; Paw = mean airway pressure; PEEPi = dynamic intrinsic positive end-expiratory pressure; $PaCO_2$ = partial pressure of arterial carbon dioxide; $FetCO_2$ = end-tidal carbon dioxide fraction.
[a] *P*‹0.01 vs HME at same PSV level; [b] *P*‹0.05 vs HME at same PSV level; [c] *P*‹0.01 vs HME at PSV of 15cm H_2O; [d] *P*‹0.05 vs HME at PSV of 15cm H_2O.

DISCUSSION:
The increase in inspiratory workload associated with the use of an HME compared with a HH is mainly due to the greater instrumental deadspace of an HME. Another contributing factor could be increased respiratory resistances which occur when using an HME. These results indicate that the choice of humidification device might influence the outcome of the weaning process in patients undergoing MV, particularly in spontaneous breathing modes. Markedly increasing the PSV level goes some way to overcoming the problems, but is really insufficient.

CONCLUSION:
In difficult, or potentially difficult, to wean patients with chronic respiratory failure, use of an HME with PSV is associated with increased respiratory workload, increased ventilatory requirements, impaired gas exchange (resulting in ventilatory acidosis) and respiratory discomfort. Therefore an HME should be avoided in this setting, and use of a HH is recommended.

C Girault, L Breton, J-C Richard, F Tamion, P Vandelet, J Aboab, J Leroy, G Bonmarchand
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KEY POINTS:

- The success of weaning from MV might be influenced by the type of humidification device used, particularly in patients who are difficult to wean.
- Use of an HME markedly increases work of breathing compared with a HH in difficult to wean patients undergoing MV.
- An increase in PSV of ≥ 8 cm H_2O is required to compensate for the increase in inspiratory effort associated with the use of an HME.
- Humidification using a HH (and not an HME) is recommended in patients with chronic respiratory failure who are classified as difficult, or potentially difficult, to wean.

DEFINITIONS:

Heat and moisture exchanger (HME)	A passive humidification device that is designed to recover some of the heat and moisture from the patient's exhaled breath, and to return a portion of the heat and moisture back to the inspired gas
Heated humidification (HH)	Active addition of heat and water vapour to inspired gases
Mechanical ventilation (MV)	Method to mechanically assist or replace spontaneous breathing when patients cannot do so on their own
Pressure support ventilation (PSV)	Ventilation designed to augment a spontaneously generated breath; the patient has primary control over the frequency of the breathing, the inspiratory time, and the inspiratory flow
Positive end-expiratory pressure (PEEP)	The amount of pressure above atmospheric pressure present in the airway at the end of the expiratory cycle during mechanical ventilation
Work of breathing	The force required to expand the lung against its elastic properties
Minute ventilation ($\dot{V}_E$)	The volume of gas that moves in and out of the lungs in one minute; it is calculated by multiplying the exhaled tidal volume by the respiratory rate
Deadspace	The space in the trachea, bronchi, and other air passages which contains air that does not reach the alveoli during respiration

For more information please contact your local Fisher & Paykel Healthcare representative

Manufacturer
Fisher & Paykel Healthcare Ltd
15 Maurice Paykel Place
East Tamaki, Auckland 2013

PO Box 14 348 Panmure
Auckland 1741
New Zealand

Tel: +64 9 574 0100
Fax: +64 9 574 0158
Email: info@fphcare.com
Web: www.fphcare.com

Australia
Tel: +61 3 9879 5022
Fax: +61 3 9879 5232

Austria
Tel: 0800 29 31 23
Fax: 0800 29 31 22

Benelux
Tel: +31 40 216 3555
Fax: +31 40 216 3554

China
Tel: +86 20 3205 3486
Fax: +86 20 3205 2132

France
Tel: +33 1 6446 5201
Fax: +33 1 6446 5221

Germany
Tel: +49 7181 98599 0
Fax: +49 7181 98599 66

India
Tel: +91 80 4284 4000
Fax: +91 80 4123 6044

Irish Republic
Tel: 1800 409 011

Italy
Tel: +39 06 7839 2939
Fax: +39 06 7814 7709

Japan
Tel: +81 3 3661 7205
Fax: +81 3 3661 7206

Northern Ireland
Tel: 0800 132 189

Spain
Tel: +34 902 013 346
Fax: +34 902 013 379

Sweden
Tel: +46 8 564 76 680
Fax: +46 8 36 63 10

Switzerland
Tel: 0800 83 47 63
Fax: 0800 83 47 54

Taiwan
Tel: +886 2 8751 1739
Fax: +886 2 8751 5625

Turkey
Tel: +90 312 354 34 12
Fax: +90 312 354 31 01

UK EC REP (EU Authorised Representative)
Fisher & Paykel Healthcare Ltd
Unit 16, Cordwallis Park
Clivemont Road, Maidenhead
Berkshire SL6 7BU, UK

Tel: +44 1628 626 136
Fax: +44 1628 626 146

USA/Canada
Tel: +1 800 446 3908
or +1 949 453 4000
Fax: +1 949 453 4001

www.fphcare.com

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