Noninvasive Ventilation

Clinical Paper Summaries

Fisher & Paykel HEALTHCARE

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AARC Clinical Practice Guideline – humidification during invasive and noninvasive mechanical ventilation: 2012

AIM:
This update of the clinical practice guideline was based on data from 184 clinical trials and systematic reviews, and 10 other articles, which investigated use of humidification during invasive and noninvasive mechanical ventilation (MV).

DETAILS:
The updated guideline recommendations, followed by the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) criteria in brackets, are detailed below.

1. Every patient undergoing mechanical ventilation should receive humidification (1A)

2. Use of active humidification is suggested for patients undergoing noninvasive ventilation (2B)

3. For active humidification during invasive mechanical ventilation, the recommended humidity is 33-44 mg H_2O/L, with a gas temperature at the circuit Y-piece of 34-41°C and a relative humidity of 100% (2B)
4. Passive humidification using a heat and moisture exchanger (HME) should provide humidity at a minimum of 30 mg H_2O/L (2B)
5. Passive humidification is not recommended for noninvasive ventilation (2C)

6. HMEs are not recommended for providing humidification to patients with low tidal volumes (2B)

7. HMEs should not be used as a protective strategy against ventilator-associated pneumonia (2B)

It is mandatory to humidify inspired gases in patients undergoing MV via an endotracheal or tracheostomy tube. In this setting, use of a heat and moisture exchanger (HME) is contraindicated in patients with the following: frank bloody or thick, copious secretions; an expired tidal volume ‹70% of the delivered tidal volume; low tidal volumes; acute respiratory distress syndrome when low tidal volumes are used; acute respiratory failure; body temperature ‹32°C; high spontaneous minute volumes (›10 L/min); during aerosol treatments when the nebulizer is placed in the circuit; during noninvasive ventilation (NIV) with large mask leaks.

HMEs:
Use of an HME increases deadspace and arterial carbon dioxide pressure (PaCO2) and can increase work of breathing (WOB) and ventilatory requirements. Provision of insufficient heat and humidification can result in complications such as dried secretions and potential blocking of the endotracheal tube (ETT). HMEs are better suited to short-term use (≤96 hours) and during transport. Devices need to be inspected regularly and replaced if secretions are contaminating the insert or filter, and/or if flow resistance has increased to a level where WOB is unacceptable. HMEs can be used safely for at least 48 hours, and may be able to be used for up to 1 week in some patient populations.

Heated humidifiers:
A heated humidifier (HH) should always be used in patients with contraindications for HME use. To deliver adequate heat and humidity it is important that the device settings are selected correctly. Inspired gas temperature should be set to ≥34°C to ‹41°C at the circuit Y-piece, with ≥33 mg/L of water vapour. Inspired gas temperature should always be measured near the patient airway and the high temperature alarm should be set to ≤41°C. Use of heated wire circuits is recommended, but heat added to the gas between the outlet of the HH and the Y-piece needs to be taken into account in calculating the relative humidity (RH) of the delivered gas. Decreased RH can result in drying of secretions in the ETT and a resulting risk of occlusion. The presence of condensation in the ETT implies that RH is 100%. If a heated wire circuit is used in an infant, the temperature probe should be located outside the incubator or away from the radiant warmer. Reusable HHs need to be disinfected between patients, and sterile water should be used to fill the water reservoir. Circuits should be changed as needed.

Device comparisons:
Data from meta-analyses show that there is little evidence for significant differences between HH and HME with respect to prevention of mortality and other complications in patients receiving MV. Similarly, there is no significant difference between the 2 devices in the incidence of ventilator-associated pneumonia.

General recommendations:
Appropriate equipment needs to be available for provision of adequate humidification of inspired gas. Humidifier performance specifications should be checked regularly. It is important that appropriately-trained individuals assess the patient and the system, evaluate humidification during MV, and exercise appropriate clinical judgment.

KEY POINTS

- Every patient undergoing mechanical ventilation should receive humidification.
- Use of active humidification is suggested for patients undergoing NIV.
- For active humidification during invasive mechanical ventilation, the recommended humidity is 33-44 mg H_2O/L, with a gas temperature at the circuit Y-piece of 34-41°C and a relative humidity of 100%.
- It is suggested that passive humidification using an HME should provide humidity at a minimum of 30 mg H_2O/L.
- Passive humidification is not recommended for NIV.
- HMEs are not recommended for providing humidification to patients with low tidal volumes.
- HMEs should not be used as a protective strategy against ventilator-associated pneumonia.

DEFINITIONS:

Deadspace	The space in the trachea, bronchi, and other air passages which contains air that does not reach the alveoli during respiration
Endotracheal tube (ETT)	A tube inserted through the mouth or nose into the trachea to maintain an unobstructed airway
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
Heated humidifier (HH)	A device that actively adds heat and water vapour to inspired gas
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
Noninvasive ventilation (NIV)	The delivery of ventilatory support without the need for an invasive artificial airway
Partial pressure of arterial carbon dioxide ($PaCO_2$)	The part of total blood gas pressure exerted by carbon dioxide gas; a measure of how much carbon dioxide is dissolved in the blood and how well carbon dioxide is able to move from the airspace of the lungs into the blood
Relative humidity (RH)	The maximum amount of water a gas can hold at a given temperature
Work of breathing (WOB)	The force required to expand the lung against its elastic properties

AM Esquinas Rodriguez, R Scala, A Soroksky, A BaHammam, A de Klerk, A Valipour, D Chiumello, C Martin, AE Holland
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Clinical review: humidifiers during non-invasive ventilation – key topics and practical implications

AIM:
To review the topic of humidification as it applies to noninvasive ventilation (NIV).

DETAILS:
In humans, the airway conditions inspired gases to core temperature and 100% relative humidity (RH) to allow optimal gas exchange at the alveolar level and protect lung tissue. On expiration, heat and moisture are recovered from expired gas. NIV provides respiratory support without bypassing the upper airway. However, the airway's usual capacity to humidify and heat inspired gases may be overwhelmed by the high flow rates used during NIV.
Inadequate humidification of inspired gases has a number of negative consequences, including anatomical and functional deterioration of the nasal mucosa, patient discomfort and poor patient tolerance. Changes in the nasal mucosa can occur relatively early during NIV, suggesting that humidification should be considered even when short-term NIV is anticipated. Inadequate conditioning of the airways can cause the accumulation of secretions resulting in airway obstruction. A number of factors need to be taken into account when assessing the need for humidification during NIV. These are discussed below.

Air leaks:
The airway mucosa recovers less heat and moisture during expiration when air leaks are present, resulting in a fall in absolute humidity (AH). The site of any leak will also affect humidity. With a nasal mask, large air leaks through the mouth increase nasal airway resistance, which is associated with the failure of acute NIV to improve gas exchange and dyspnoea and with unsuccessful acclimatization to chronic NIV therapy. Effective humidification has been shown to attenuate the increase in nasal airway resistance associated with mouth leak during nasal continuous positive airway pressure (CPAP).

Patient interfaces:
Nasal and facial masks are the most common interfaces used to deliver NIV. Nasal masks are better tolerated for chronic therapy but have more air leaks than face masks, which can contribute to inadequate conditioning of inspired gas. Any leak, whether intentional (around the mask) or unintentional (within the mask or circuit) impacts on RH because of the compensatory increase in flow. Changes in RH related to mouth leaks can be eliminated by the use of an oro-nasal mask, and this type of interface is probably the best choice to maximize the success of NIV in a number of acute settings. Essentially, the humidity of inspired gases needs to be carefully adjusted based on type of interface used for NIV, the size of its internal space and the resulting leak pattern.

Type of ventilator:
Use of a ventilator in a NIV mode provides a high inspiratory flow to compensate for the inspiratory demand of patients with respiratory problems. ICU ventilators obtain dry gas from outlets and deliver lower humidity than ventilators that compress room air. The higher the oxygen fraction delivered during NIV, the greater the risk of inadequate gas conditioning.

Ambient temperature:
The effects of ambient temperature are likely to be negligible compared with other factors (interface, air leaks, inspired oxygen fraction, respiratory rate, humidifier use), and only really need to be considered for patients receiving NIV who sleep in a very cold environment.

Temperature of inhaled gas:
The temperature of inspired gas is an important determinant of whether it reaches body temperature at the alveolar level. Gas temperature is affected by the ventilator power source and the level of inspiratory positive airway pressure. The results of a bench study suggested that a heated humidifier (HH) set at its maximum temperature was the most effective approach for delivering adequate humidity during NIV.

Airflow at the entrance to the humidifier:
One of the key physical factors affecting airway humidity is the airflow entering the humidification chamber of a HH. At very high flow rates, it may be difficult for a HH to provide adequate humidification of inspired gases.

Type of humidifier:
In patients undergoing NIV, a HH has been shown to offer a number of advantages over a heat and moisture exchanger (HME), including reduced work of breathing, minimal deadspace and less CO2 retention. These benefits are particularly relevant in the acute setting. Another situation where a HH performs better than an HME is in the presence of excessive air leaks. There are currently no consistent recommendations for one humidification device over another, but survey data suggest that a HH is used more often than an HME for acute application of NIV. Regardless of the ventilator settings, the RH within a NIV circuit is substantially lower than the ambient RH and this is significantly lower at higher inspiratory positive airway pressures. Use of a HH has been shown to increase RH under these conditions.

Humidification and CPAP in obstructive sleep apnoea (OSA):
CPAP therapy is the gold standard for patients with OSA. Although good compliance with CPAP reduces morbidity and mortality, adherence to the therapy is a significant clinical problem. Side effects including nasal congestion, dry nose or throat, and discomfort associated with the cold are cited as problematic by up to 65% of CPAP recipients. Humidification of inspired air can largely prevent these unwanted events, and most current CPAP devices have a built-in HH system. The American Academy of Sleep Medicine recommends the use of a HH to improve compliance and adherence with CPAP therapy in patients with OSA who complain of upper airway symptoms that have not responded to other interventions.

CONCLUSION:
Adequate gas conditioning is an essential component of NIV. A number of factors contribute to inadequate humidification. Appropriate use of a humidification system helps to prevent NIV-induced nasal dryness. However, a number of questions remain unanswered, including when to use a humidifier during acute or chronic NIV, the most appropriate humidification device in different settings, the interaction between humidification and the underlying disease process, and the influence of different ventilators on humidity delivery.

KEY POINTS

- Humidification is important in the conditioning of inspired gases during NIV.
- Inadequate airway conditioning has been associated with reduced ciliary activity, and increased mucus secretion and local blood flow resulting in increased nasal resistance. This can lead to airway obstruction.
- A high level of air leak causes increased flow rates which may reduce the delivery of humidity during NIV.
- A HH has a number of advantages over an HME for humidity delivery during NIV, particularly in the acute setting.
- The American Academy of Sleep Medicine recommends the use of a HH to improve compliance and adherence with CPAP therapy in patients with OSA who complain of upper airway symptoms that have not responded to other interventions.

DEFINITIONS:

Absolute humidity (AH)	The amount of water vapour in a given volume of gas
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 the ventilatory circuit
Dead space	The space in the trachea, bronchi, and other air passages which contains air that does not reach the alveoli during respiration
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
Heated humidifier (HH)	A device that actively adds heat and water vapour to inspired gas
Nasal airway resistance	A measure of the degree of resistance to airflow through the nose
Noninvasive ventilation	The delivery of ventilatory support without the need for an invasive artificial airway

(NIV)	
Obstructive sleep apnoea (OSA)	Collapse of the upper airway structures during sleep, resulting in disruption of breathing of 10 seconds or longer occurring periodically throughout sleep
Relative humidity (RH)	The maximum amount of water a gas can hold at a given temperature
Work of breathing (WOB)	The force required to expand the lung against its elastic properties

*in*Science Communications

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Clinical factors affecting inspired gas humidification and oral dryness during noninvasive ventilation

AIM:
To investigate the effect of inspired gas humidification on oral dryness in critically ill patients receiving noninvasive ventilation (NIV) and to assess the effects of heated humidifier (HH) settings, ventilator settings and gas leakage on the hygrometric properties of inspired gas.

METHOD:
Two studies are reported in this publication. In the prospective clinical study, 23 critically ill patients (12 males; median age 66 years) in acute respiratory failure undergoing NIV, provided by a bilevel positive airway pressure ventilator support device (BiPAP Vision; Respironics) and a full-face mask with a swivel exhalation port (Comform Full2; Respironics), were randomised to HH settings of medium humidity (level 5; 26–28°C at the mask) or maximum humidity (level 9; 33–36°C at the mask). The HH (PMH 1000; Pacific Medico) was connected to the NIV mask via a standard 180-cm smooth-bore tube. The primary objective was to measure oral dryness, assessed using a numerical rating scale (NRS) from 0 (normal) to 10 (most severe dryness) and an oral moisture-checking device (Moisture Checker Mucus; Scalar).

In the bench study, the effects of HH settings, ventilator settings and gas leakage on absolute humidity was investigated in a simulated breathing mannequin experiment. A two-chamber lung model (TTL; Michigan Instrument) was set with resistance of 10 cm H_2O/L/sec and compliance of 50 mL/cm H_2O. The NIV ventilator was set to spontaneous/timed mode with a respiratory rate of 4 breaths/min, an inspiratory time of 1.0 second, a fraction of inspired oxygen (FiO_2) of 0.21, 0.6 and 1.0, an expiratory positive airway pressure (EPAP) of 5, 10 and 15 cm H_2O and an inspiratory positive airway pressure (IPAP) of 5, 10 and 20 cm H_2O. The HH was set to either medium (level 5) or maximum (level 9) humidity, with or without a gas leak.

RESULTS:
In the clinical study, oral moistness decreased significantly from baseline after 12 and 24 hours of NIV in the medium humidity group (both $p<0.05$). After 24 hours this reduction was statistically significant when measured using both the NRS and the oral moisture-checking ($p<0.05$ and $p<0.01$ vs maximum humidity group, respectively). In contrast, no changes in oral moistness were observed when the HH was set to maximum humidity. Data for the bench study (study 2) are reported in the table.

Bench study	Absolute humidity (mg H_2O/L)		
	No HH	Medium HH setting	Maximum HH setting
Ventilator settings [mean ± SD]			
FiO_2			
0.21	10.9 ± 0.6[ab]	21.5 ± 2.4[ab]	30.0 ± 1.5[ab]
0.6	5.0 ± 0.4[a]	17.9 ± 2.8[a]	28.1 ± 1.8
1.0	0.1 ± 0.0	13.1 ± 3.3	25.8 ± 2.7[a]
EPAP (cm H_2O)			
5	5.4 ± 4.8	19.3 ± 4.2[cd]	29.3 ± 2.0[cd]
10	5.3 ± 4.8	17.1 ± 4.6[c]	28.1 ± 2.8[c]
15	5.3 ± 4.9	16.0 ± 4.5	26.7 ± 2.7
Leak			
Without	5.0 ± 4.4	19.6 ± 3.9[e]	29.3 ± 1.9[e]
With	5.6 ± 4.9	15.3 ± 4.0	26.7 ± 2.6

EPAP = expiratory positive airway pressure; FiO_2 = fraction of inspired oxygen; HH = heated humidifier; SD = standard deviation.
[a] $p<0.01$ vs FiO_2 1.0; [b] $p<0.01$ vs FiO_2 0.6; [c] p.01 vs EPAP 15 cm H_2O; [d] $p<0.01$ vs 1cm H_2O; [e] $p<0.01$ vs with leak.

DISCUSSION:
This study is the first to include an objective measure of oral dryness in patients with acute respiratory failure undergoing NIV. Although the upper airway is not bypassed during NIV, this study showed that patients with acute respiratory failure have a low level of mean oral moistness prior to NIV initiation. Therefore, even though the absolute humidity levels provided by a HH on medium setting are theoretically enough to prevent airway dryness, this was insufficient to overcome an existing deficit. Therefore, absolute humidity of 25 mg H_2O/L may be needed to prevent oral dryness during NIV in patients with acute respiratory failure. One potential limitation of using the maximum HH setting is the formation of condensation in the tubing, which was noted in this study and could interfere with ventilator performance and patient comfort. The findings of the bench study were consistent with previous research documenting lower absolute humidity when EPAP is increased or an air leak is present.

CONCLUSION:
The HH setting significantly influences the absolute humidification of inspired gases, and affects oral dryness during NIV. To prevent drying of the oral mucosa during NIV in critically ill patients with acute respiratory failure, use of the maximal humidity setting on a HH is recommended.

KEY POINTS:

- Use of the maximal setting (33–36°C at the mask), but not the medium setting (26–28°C at the mask), on a HH prevented the development of oral dryness during NIV in critically ill patients with acute respiratory failure.
- Absolute humidity delivered by a HH is affected by FiO_2, EPAP, IPAP and the presence of air leaks.

DEFINITIONS:

Acute respiratory failure	A syndrome in which the respiratory system fails in one or both of its gas exchange functions: oxygenation and carbon dioxide elimination. Acute respiratory failure is characterised by life-threatening changes in arterial blood gases and acid-base status
Expiratory positive airway pressure (EPAP)	The maximum pressure exerted during expiration
Fraction of inspired oxygen (FiO_2)	The fraction of oxygen in inspired gas from 0.0 (0%) to 1.0 (100% oxygen)
Heated humidifier (HH)	A device that actively adds heat and water vapour to inspired gas
Inspiratory positive airway pressure (IPAP)	The maximum pressure exerted during inspiration
Numerical rating scale (NRS)	A rating scale which details a set of responses where the alternative answers are ordered from low to high and are assigned a numerical value

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Nasal inflammation in sleep apnoea patients using CPAP and effect of heated humidification: a randomised, sham-controlled, crossover study

AIM:
To examine the nature of nasal side effects of continuous positive airway pressure (CPAP) in patients with obstructive sleep apnoea (OSA), and the effect of heated humidification on these symptoms.

METHOD:
Patients with OSA were eligible for inclusion in this randomised, crossover, sham-controlled study if they had symptomatic, CPAP-related nasal obstruction and an apnoea-hypopnoea index of >15 events/hour.

Patients were randomized to receive nasal CPAP therapy [S7 Escape™; Resmed] with heated humidification [HumidAire 2i™; Resmed] for 3 weeks followed by nasal CPAP therapy with sham-heated humidity (achieved by turning off the heating unit and not adding water to the chamber) for a further 3 weeks, or the same two therapies in the reverse sequence. There was no washout period between the regimens.

Patients were assessed at baseline, and at the end of each 3-week treatment period. At each study visit, five nasal symptoms (i.e. rhinorrhoea, post-nasal drip, sneezing, impaired sense of smell and nasal blockage) were assessed as being present/increased over baseline (score of 1) or absent/not increased (score of 0) with scores combined to give a total nasal symptom score of 0-5, and anterior rhinomanometry (in seated and supine positions), nasal lavage and nasal mucosa biopsies were performed.

RESULTS:
Twenty patients were enrolled in the study, and 10 patients were randomised to each study arm; all patients completed the study. Heated humidification was significantly better than sham-heated humidification in patients with OSA and symptomatic, CPAP-related nasal symptoms with respect to nasal symptom scores, supine nasal resistance, levels of inflammatory markers in nasal lavage fluids and improvement of some histopathological features in nasal mucosa tissue after 3 weeks' treatment (see table). No difference was seen between the two groups in seated nasal resistance. Possible carryover or treatment effect was not thought to have influenced study results.

Data at the end of 3 weeks' treatment	Type of humidification		
	Heated	Sham-heated	*P* value
Nasal symptom score	2.3 (2.0-3.0)	3.4 (3.0-4.0)	<0.001
Supine nasal resistance (cm $H_2O \bullet L^{-1} \bullet s$)	2.3 (2.0-2.5)	2.8 (2.4-3.5)	<0.001
Level of nasal lavage inflammatory mediators (pg/mL)			
IL-6	1.2 (1.0-1.5)	1.5 (1.3-1.6)	<0.001
IL-12	7.2 (6.2-7.9)	8.3 (7.4-9.1)	0.005
TNF-α	1.8 (1.7-2.1)	2.6 (1.9-2.7)	0.001
Nasal mucosa pathology n (%)			
Inflammation:			
Absent	8 (40)	0 (0)	<0.01
Mild	8 (40)	6 (30)	NS
Moderate	4 (20)	8 (40)	NS
Severe	0 (0)	6 (30)	<0.05
Fibrosis:			
Absent	6 (30)	0 (0)	<0.05
Mild	6 (30)	10 (50)	NS
Moderate	8 (40)	6 (30)	NS
Severe	0 (0)	4 (20)	NS
Mucous glands:			
Absent	4 (20)	0 (0)	NS
Mild	10 (50)	8 (40)	NS
Moderate	6 (30)	8 (40)	NS
Severe	0 (0)	4 (20)	NS

IL = interleukin, NS = not significant, TNF-α = tumour necrosis factor-α. Apart from nasal pathology, all values are median (interquartile range).

DISCUSSION:
Nasal discomfort is one of the most frequently occurring side effects related to CPAP and may result in poor long-term compliance. Although the effects of heated humidification on symptoms and compliance with CPAP therapy have been assessed, the effects of humidification on nasal airway pathophysiology and therefore the mechanism by which nasal symptoms are decreased when humidification is added to CPAP have not been determined.

The temporal relationship between improvements in inflammatory parameters and beneficial changes in symptom score in this study implies that attenuation of nasal mucosal inflammation is an important mechanism for the beneficial effects of heated humidification on nasal symptoms during CPAP.

It has been suggested that CPAP represents a second mucosal injury to already damaged nasal tissues. Therefore, the addition of humidification could compensate for existing deficits, attenuating the development of nasal symptoms. Another possibility is that cold, dry air has a toxic effect on the nasal epithelium and mediator cells, and that humidification prevents such cellular toxicity and associated detachment, shedding and mediator release. Mediator release may also be prevented by humidification because it stops any changes to the osmolarity of mast cell extracellular fluid that could result in mediator release. Finally, a previous study suggested that epithelial detachment following airflow of cold, dry air is likely to be linked to a defect in mucosal water transportation, rather than a sheer force stimulus exerted by the airflow itself. Therefore, it is possible that this may also explain the attenuation of nasal inflammation shown in the present study.

CONCLUSION:
CPAP has an inflammatory effect on the nasal mucosa of patients with OSA and symptomatic, CPAP-related nasal symptoms. In this patient population, CPAP with heated versus sham-heated humidification was associated with a reduced incidence of nasal symptoms, and with decreased supine nasal resistance, nasal lavage cytokine levels, and nasal mucosa inflammation and fibrosis. Further studies are warranted.

KEY POINTS:
- CPAP-related nasal symptoms appear to be inflammatory in nature.
- CPAP with heated humidification improves nasal symptomatology and attenuates pre-existing nasal mucosa inflammation.

DEFINITIONS:

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 the ventilatory circuit
Obstructive sleep apnoea (OSA)	Collapse of the upper airway structures during sleep, resulting in disruption of breathing in 10 seconds or longer occurring periodically throughout sleep
Rhinorrhoea	Excessive discharge of mucous from the nose

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JM Tuggey, M Delmastro, MW Elliott
Respiratory Medicine 2007; 101: 1874-1879

The effect of mouth leak and humidification during nasal non-invasive ventilation

AIM:
To investigate the effect of deliberate mouth leak on tidal volume (V_T), nasal resistance (R_N) and comfort scores during nasal noninvasive ventilation (NIV), with and without heated humidification, in healthy volunteers.

METHOD:
Sixteen healthy volunteers were included in this randomised, crossover study. A noninvasive turbine ventilator (VPAP II; ResMed) was used, with pressure increased to 20 cmH_2O inspiratory and 5 cmH_2O expiratory positive airway pressure; maximum inspiratory time was set at 3 seconds. Heated humidification was delivered using the HC100 (Fisher & Paykel) set at 37ºC. To achieve deliberate mouth leak, subjects were instructed to keep their mouth open so that continuous airflow could be felt through the mouth (mouth leak was maintained for 5 minutes). Flow, mask pressure and respiratory rate were measured using a pneumotachometer fitted between the nasal mask and exhale valve. Oropharyngeal pressure was measured using a pressure transducer connected to 3mm tubing inserted through the mouth and positioned in the oropharynx. Patient comfort was assessed using a visual analogue scale before, during and after mouth leak.

RESULTS:
Mean V_T prior to mouth leak was 1035mL, which fell to a nadir of 911mL 3 minutes after cessation of the leak (p=0.004 vs pre-leak) and had returned to pre-leak levels within 10 minutes. Pre-leak R_N was 4.4 cmH_2O L sec^{-1}, which increased to a peak of 7.6 cmH_2O L sec^{-1} 2 minutes after mouth leak (p=0.01 vs pre-leak) then fell to pre-leak levels within 10 minutes. Use of heated humidification significantly attenuated the increase in R_N and the decrease in V_T that occurred after a period of mouth leak during nasal NIV. Visual analogue scale scores (before, during and after mouth leak) were significantly higher (indicating greater comfort) when NIV was given with versus without humidification. In addition, the decrease in comfort score during mouth leak was significantly less with the addition of heated humidification.

DISCUSSION:
This is the first study assessing the effect of mouth leak during nasal NIV on V_T. Mouth leak results in an increase in nasal resistance, which in turn is associated with a small (12%) but statistically significant reduction in expired V_T. The duration and severity of mouth leak in this study are similar to those that occur in patients undergoing nocturnal nasal NIV at home. The increase in R_N that occurred might gradually worsen during longer periods of NIV, such as overnight, thus having an increasingly deleterious effect on V_T. The addition of heated humidification during nasal NIV attenuated the effects of mouth leak on R_N and V_T, and improved patient comfort at all timepoints.

CONCLUSION:
Mouth leak during nasal NIV has an adverse effect on R_N and V_T. This can be minimised by the addition of heated humidification, which also improves overall patient comfort.

KEY POINTS:

- Mouth leak increases R_N during nasal NIV.
- Increased R_N during mouth leak in subjects undergoing nasal NIV is associated with deleterious effects on V_T.
- The adverse effects of mouth leak on R_N and V_T can be attenuated by the addition of heated humidification.
- Heated humidification increases patient comfort at all times during nasal NIV.

DEFINITIONS:

Tidal volume (V_T)	The volume inspired or expired per breath
Noninvasive ventilation (NIV)	The delivery of ventilatory support without the need for an invasive artificial airway
Heated humidification	Active addition of heat and water vapour to inspired gases

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Inspissated secretions: a life-threatening complication of prolonged noninvasive ventilation

AIM:
To report a life-threatening complication of prolonged NPPV – the formation of a mass of inspissated secretions occluding the airway, leading to respiratory distress. In addition, to compare the benchtop humidity output of a CWPH with that of an HH.

BACKGROUND:
NPPV is accepted for the treatment of patients with acute and chronic respiratory failure, and may decrease the need for endotracheal intubation and associated complications including pneumonia, barotrauma, and aspiration. NPPV is considered relatively safe, with the most common complications including discomfort, pressure sores, conjunctivitis and dryness in the upper airways.

CASE SUMMARY:
A 66-year-old alcoholic White male underwent abdominal peritoneal resection for rectal carcinoma. His postoperative recovery was complicated by renal failure and respiratory insufficiency secondary to volume overload. The patient was unable to achieve ›90% oxygen saturation with the use of a high-flow nonrebreather face mask, but was reluctant to be intubated, so a trial of CPAP was undertaken. Following a 48-hour period of respiratory stability the patient was again unable to maintain oxygen saturation ›90% with CPAP, and a trial of NPPV was initiated because the patient still refused to be intubated.

NPPV was initiated using the BiPAP S/T 30 (Respironics) in the spontaneous mode, with an inspiratory positive airway pressure of 10 cm H_2O, and end-positive airway pressure of 5 cm H_2O, applied with a full face mask. Substantial improvement in clinical status and oxygen saturation were noted, but an oxygen bleed-in of 40 L/min was required to maintain oxygen saturation ›90%. The patient tolerated only brief periods of independence from NPPV over the following 4 days.

After 6 days of NPPV the patient was noted to have a dry oral mucosa and dried secretions in the mouth and posterior pharynx. Therefore, NPPV was discontinued and substituted with an 80% aerosol mask. After 1 hour the patient developed progressively worsening respiratory stridor associated with tachypnoea and increased WOB. No improvement was observed with re-institution of NPPV. In addition, the patient complained of a foreign body sensation in the back of the throat so the nasogastric tube was removed. Respiratory distress developed immediately and intubation was attempted revealing a large object occluding the vocal cords. The object was removed using forceps and the patient returned to a 90% aerosol mask. A complete respiratory recovery occurred over the next several days without further NPPV.

The removed object was a 5x7 cm mass consisting of inspissated secretions and blood. It seems that the mass had partially fractured causing incomplete airway obstruction, and that subsequent removal of the nasogastric tube allowed the remainder of the mass to detach from the posterior pharynx.

DISCUSSION:
Previous studies have suggested reductions in intubation, complications, length of stay, and ICU mortality associated with NPPV. In this report, NPPV using the Respironics BiPAP S/T-D30 unit resulted in significant and prolonged improvements in WOB and respiratory rate in a patient with respiratory insufficiency secondary to renal failure and volume overload. However, prolonged NPPV resulted in the formation of a large mass of inspissated secretions that lead to life-threatening airway compromise.

The manufacturer's recommendations for NPPV using the BiPAP S/T-D30 unit suggest the use of an oxygen flow ≤15 L/min; however higher flows (up to 40 L/min) may be required to achieve adequate delivery in some patients with hypoxemic respiratory failure requiring additional supplemental oxygen. In this scenario, the CWPH may not provide adequate humidification of inspired gas. An HH may provide better humidification by increasing the relative humidity of the gas flow.

HH vs CWPH benchtop comparison: A bench-top comparison of the humidity output of the flat Respironics humidifier with that of an HH was performed under similar scenarios. Using 2 Whisper Swivels (Respironics) and 30 L/min oxygen flow the CWPH produced 33-34% RH at 23.8°C, whereas the HH produced 100% RH at 28.1°C. Based on these results, the authors have instituted a policy of utilizing HH at a temperature of 28°C when using NPPV with high-flow supplemental oxygen.

CONCLUSION:
Life-threatening airway compromise is a previously unreported complication of NPPV. It is likely that this type of complication may increase in frequency as the use of NPPV continues to grow. Such events could be limited by a heightened sense of awareness of this possibility, limiting the duration of NPPV, and the use of adequate humidification.

KEY POINTS:

- The use of NPPV in patients with respiratory failure continues to grow.
- NPPV avoids complications associated with intubation and is relatively safe.
- Some patients may require prolonged NPPV with high oxygen flow.
- Prolonged NPPV with high oxygen flow may result in the formation of inspissated secretions leading to life-threatening airway obstruction, despite the use of CWPH.
- Benchtop studies demonstrate that HHs provide superior humidification to CWPH.
- Adequate humidification, limiting the duration of NPPV and heightened awareness of the possibility of inspissated secretions may limit the frequency of this complication.

DEFINITIONS:

Cold water passover humidifier (CWPH)	A device which adds water vapour to inspired gases
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 the ventilatory circuit
Heated humidifier (HH)	A device which actively adds heat and water vapour to inspired gases
Intensive care unit (ICU)	A hospital facility providing intensive nursing and medical care for critically ill patients
Inspissated secretions	Secretions that have been dried-out or thickened by excessive evaporation
Non-invasive positive pressure ventilation (NPPV)	The delivery of positive pressure ventilatory support without the need for an invasive artificial airway
Relative humidity (RH)	The maximum amount of water a gas can hold at a given temperature
Tachypnoea	Rapid shallow breathing
Work of breathing (WOB)	The force required to expand the lung against its elastic properties

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Effects of humidification on nasal symptoms and compliance in sleep apnea patients using continuous positive airway pressure

AIM:
To evaluate the effects of heated and cold passover humidification on nasal symptoms and compliance in patients with obstructive sleep apnoea (OSA) being treated with continuous positive airway pressure (CPAP).

METHOD:
Forty-seven patients were enrolled in the study, and thirty-eight completed the 8-week protocol. During CPAP (Sullivan V Elite Real Time Clock; ResMed, with a Sullivan Mirage nasal mask), patients received humidification via a heated humidifier (HC100; Fisher & Paykel) or a cold passover humidifier (Oasis; Respironics) for 3 weeks; the study had a crossover design and there was a 2-week washout period between treatments. Patients were questioned about chronic nasal symptoms and side effects, completed the Epworth Sleepiness Scale (ESS), and used a 100mm Likert scale to rate how satisfied they were with CPAP and how refreshed they felt upon awakening. Compliance data were downloaded from the CPAP device, and patient preference was determined at the end of the study.

RESULTS:
Key outcome measures are reported in the table below. With respect to side effects, patients reported that dry mouth or throat and dry nose interfered to a greater extent when CPAP was used without humidity compared to when heated humidification was used. There was no significant difference in these side effects between cold passover humidification and no humidification. Seventy-six percent (29/38) of patients preferred the heated humidifier to the cold Passover humidifier.

	Type of humidification		
	Without humidification	**Cold passover humidification**	**Heated humidification**
Usage (hours per night)	4.93	5.15	5.52[c]
ESS score	6.7[a]	7.2[a]	6.2[a]
Feeling upon awakening	62.0	68.9	74.0[d]
Satisfaction with CPAP*	62.3	72.9[b]	73.9[d]
Global score for adverse side effects	6.5	6.2	4.9

* Assessed on a 100mm Likert scale from 0 (poorest) to 100 (highest possible rating).
[a] p<0.0001 vs baseline; [b] p=0.05 vs without humidification; [c] p = 0.008 vs without humidification; [d] p = 0.02 vs without humidification.

DISCUSSION:
Usage of CPAP was increased when heated humidity was added to therapy; this was not the case for cold passover humidification. The increase in usage is most likely due to an improvement in nasal symptoms when heated humidification was added to CPAP. This is the first study to show that compliance with CPAP therapy can be improved by an intervention other than patient education and support. While the magnitude of the improvement was smaller than that in previous intervention studies, it is still considered to be clinically relevant. Although humidification is usually only added to CPAP after the occurrence of persistent and severe upper airway side effects, addition of heated humidification at the start of CPAP therapy has the potential to be associated with better compliance gains.

CONCLUSION:
Use of a heated humidifier during CPAP therapy improves compliance. Patient satisfaction with CPAP increases when humidity is added.

KEY POINTS:
- It is widely recognised that compliance with CPAP therapy is less than optimal.
- This is the first study to show that compliance with CPAP therapy can be improved by an intervention other than patient education and support.
- the increase in compliance observed with the addition of heated humidification is most likely due to associated improvements in nasal symptoms.
- Delaying the introduction of heated humidification during CPAP might reduce potential benefits associated with compliance - the beneficial effects of heated humidification could be achieved earlier if initiated at the same time as CPAP.

DEFINITIONS:

Heated humidifier	A device that actively adds heat and water vapour to inspired gas
Cold passover humidifier	A device that adds water vapour to inspired gas by having the air flow over a reservoir of cool water
Obstructive sleep apnoea (OSA)	Collapse of the upper airway structures during sleep, resulting in disruption of breathing of 10 seconds or longer occurring periodically throughout sleep
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 the ventilatory circuit
Epworth sleepiness scale	A score of 10 or more is considered sleepy. A score of 18 or more is very sleepy Used to determine the level of daytime sleepiness

E Saatci, DM Miller, IM Stell, KC Lee, J Moxham
European Respiratory Journal 2004; 23:129-135

Dynamic dead space in face masks used with noninvasive ventilators: a lung model study

AIM:
To evaluate the effects of different face masks and different noninvasive ventilators using different mode settings on V_D/V_T using a lung model.

METHOD:
Eighteen NIV face masks and one total face mask were tested, as were five commonly available ventilators. The masks were connected to the ventilators via their recommended circuits and ventilators were set to their most sensitive triggering level for both inspiration and expiration. $V_{D,phys}$ of the lung model (mannequin head and trachea) was 141 mL (equivalent to a $V_{D,phys}/V_T$ ratio of 0.32, which is the expected value in patients). Lung model settings were 19 breaths/min with a V_T of 440 mL.

RESULTS:
Masks: During spontaneous breathing, there was an increase in V_D/V_T. The average increase in V_D was 33.82%. Differences between face masks were minor. During NIV the masks with the lowest deadspace all had expiratory ports over the nasal bridge, compared with at the cheeks or in the expiratory port. However, this decrease was smaller when PEEP was not used. There was no statistically significant correlation between the volume of the face mask and deadspace.
Ventilators: All ventilator modes reduced V_D/V_T compared to spontaneous breathing with a face mask. The use of bi-level and CPAP modes during NIV reduced V_D/V_T to values close to $V_{D,phys}$. This reduction occurred to a lesser extent with other ventilator modes such as pressure-assist and pressure-support ventilation without PEEP (see table). These differences are statistically significant because the variation within the bench model is very low.

NIV Ventilator	Ventilation mode	IPAP	EPAP	V_D/V_T
Respironics BIPAP S/T	Bi-level	16	4	0.26 – 0.39
Breas 401	Pressure-support	16	0	0.34 – 0.44
NIPPY 1	Pressure-assist	16	0	0.33 – 0.44
Puritan Bennett 335	Bi-level	16	4	0.26 - 0.39
Puritan Bennett 335	CPAP	5	5	0.26 – 0.39
ResMed Sullivan VPAP S/T	Bi-level	16	4	0.26 – 0.40

DISCUSSION:
The increase in deadspace that occurs during NIV depends on both the design of the mask and the mode of ventilation, rather than the static volume within the face mask. The increase in V_D/V_T is due to an increase in $V_{D,ap}$ caused by low pressure in the face mask during expiration. This makes gas elimination via the ports less effective, directly increasing $V_{D,ap}$. The position of the exhaust ports increase flushing and create a beneficial flow pathway through the mask, which reduces deadspace particularly in the presence of PEEP. The reduction of V_D/V_T to values close to $V_{D,phys}$ during NIV using bi-level and CPAP modes is due to the PEEP during expiration phase moving the elimination point in the mask closer to the patient (i.e. the flushing out of the mask during expiration all but reduced $V_{D,ap}$ to zero).

CONCLUSION:
NIV face masks increase $V_{D,phys}$ during spontaneous ventilation. Face masks with exhaust ports or perforations over the nasal bridge, compared with at the cheeks or in the expiratory port, work best to increase flushing and decrease deadspace.

KEY POINTS:
- During spontaneous breathing, there was an increase in total dynamic deadspace due to the mask. Low pressure in the face mask during expiration made gas elimination via the ports less effective, directly increasing the deadspace due to equipment. The average increase in deadspace was 33.82%.
- Compared to spontaneous breathing, all modes of ventilation decreased total dynamic deadspace.
- During CPAP and bi-level ventilation, exhalation ports over the nasal bridge caused a greater reduction in $V_{D,phys}$ and $V_{D,ap}$ compared with masks with exhalation ports on the cheeks or in the expiratory port.
- There was no correlation between the volume in the mask and the deadspace, because the design of the mask had a far greater effect than the enclosed volume.

DEFINITIONS:

Apparatus deadspace ($V_{D,ap}$)	Also called instrumental deadspace. The volume of deadspace added by the equipment
Bi-level	Where two pressure levels are applied – one for inspiration and a lower pressure for expiration
Continuous positive airway pressure (CPAP)	Continuous positive airway pressure – ventilation where one positive pressure is applied for the whole respiratory cycle
Deadspace (V_D)	$V_{D,phys} + V_{D,ap}$
Elimination point	The point in a breathing system beyond which alveolar gas is not returned to the alveoli and can not contribute to the deadspace
Expiratory positive airway pressure (EPAP)	The maximum pressure exerted during expiration
Inspiratory positive airway pressure (IPAP)	The maximum pressure exerted during inspiration
Physiological deadspace ($V_{D,phys}$)	The volume of the conducting airways of the nose, mouth and trachea, but not the alveoli, representing the portion of inspired gas unavailable for exchange of gases with pulmonary capillary blood. This is usually around 25% of tidal volume
Positive end-expiratory pressure (PEEP)	The amount of pressure above atmospheric pressure present in the airway at the end of the expiratory cycle. Pressure is applied to keep collapsed alveoli open
Pressure assist	As in Pressure Support below except that the inspiratory time is set
Pressure support	Provides a set positive pressure on inspiration. The patient triggers the breath and regulates their own respiratory rate and tidal volume
Tidal volume (V_T)	The lung volume representing the normal volume of air inspired (or expired) in one breath, when no extra effort is applied
Total dynamic deadspace (V_D / V_T)	The ratio which represents how deadspace changes, according to the tidal volume

F Lellouche, C Pignataro, SM Maggiore, E Girou, N Deye, S Taillé, M Fischler, L Brochard
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Short-term effects of humidification on respiratory pattern and arterial blood gases during noninvasive ventilation

AIM:
To compare the short-term impact of using heat and moisture exchangers (HME) or heated humidifiers (HH) on arterial blood gases and breathing pattern during noninvasive ventilation (NIV) for hypercapnic or hypoxaemic acute respiratory failure.

METHOD:
This prospective, randomized, crossover study included patients admitted to the intensive care unit (ICU) for recent dyspnoea exacerbation and one of the following: respiratory rate ⩾25 breaths/min, partial pressure of arterial oxygen (PaO2) ‹60 mmHg with room air, or arterial pH ‹7.38. Ventilatory support was provided based on local recommendations. All patients received NIV via an ICU ventilator. A HH (MR850; Fisher & Paykel Healthcare) was placed in the inspiratory line according to the manufacturer's recommendations or a HME (Hygrobac; DAR) was placed at the Y-piece. Each humidification device was used for 30 min then patients were crossed over to the other device; order of use was randomized. Ventilatory parameters were recorded and arterial blood gases measured during the last 5 minutes of each 30-minute study period. Three separate groups of patients were defined: hypercapnia with respiratory acidosis, hypercapnia without respiratory acidosis and hypoxaemia without hypercapnia.

RESULTS:
Eighty-one patients (54 male and 27 female; mean age 63±14 years) were included in the study. Mean Simplified Acute Physiology Score (SAPS II) was 41±28. Indications for NIV were acute hypoxaemic respiratory distress (n=26), acute exacerbation of chronic obstructive pulmonary disease (n=28), post-extubation respiratory distress (n=7), cardiopulmonary oedema (n=12) or other (n=8). Ventilatory settings were: pressure support level 14±3 cm H2O, positive end-expiratory pressure 5±2 cm H2O and fraction of inspired oxygen 51±23%.

In all groups, the HME caused a significant increase in the partial pressure of arterial carbon dioxide ($PaCO_2$) even though there was significantly higher minute ventilation. This was more evident in the hypercapnic patients as shown in the table by patient subgroup. There were no statistically significant differences between HH and HME for PaO_2 or expiratory tidal volume in any of the patient groups.

Median (interquartile range)	pH	$PaCO_2$ (mmHg)	RR (breaths/min)	VE (L/min)
Hypercapnia with acidosis				
HME	7.31 (7.28-7.34)	60 (52-70)	27 (22-33)	13.8 (11.1-15.1)
HH	7.34 (7.30-7.36)a	56 (47-64)a	22 (18-28)a	11.4 (9.4-12.1)a
Hypercapnia without acidosis				
HME	7.41 (7.39-7.44)	50 (47-55)	23 (18-28)	15.1 (11.5-17.0)
HH	7.42 (7.40-7.46)a	48 (45-53)a	20 (18-26)a	12.2 (10.0-16.0)a
Hypoxaemia				
HME	7.43 (7.38-7.45)	36 (34-40)	30 (26-34)	17.3 (14.5-23.0)
HH	7.44 (7.41-7.47)a	35 (32-39)a	29 (24-32)b	16.3 (11.7-19.8)a

RR = respiratory rate; VE = minute ventilation. a p‹0.001 vs HME; b p‹0.01 vs HME.

In the 19 patients for whom arterial blood gas data were available prior to initiation of NIV, CO_2 removal was only improved during use of the HH. There was no effect of treatment order on the results for $PaCO_2$ variations. Univariate analysis showed that the most influential factors on the difference in $PaCO_2$ between the HH and HME groups were the presence of hypercapnic respiratory failure, initial $PaCO_2$ level and expired tidal volume.

DISCUSSION:

This study was conducted under conditions that were similar to those encountered in clinical practice. The findings showed that use of a HME to provide humidification during NIV had a negative impact on short-term CO_2 elimination compared with using a HH, particularly in patients with hypercapnia. It is likely that this is due to the increase in deadspace; the HME device deadspace was 95 mL. It has already been shown that deadspace needs to be minimized during NIV to reduce work of breathing and decrease $PaCO_2$. The data from this study, however, do not allow conclusions to be drawn regarding the comparative impact of using a HME versus HH on the outcome and efficacy of NIV.

CONCLUSION:

Use of the HME device to provide humidification during NIV had a short-term negative impact on CO_2 elimination and minute ventilation, probably due to the increased dead space.

KEY POINTS

- Use of a HME to provide humidification during NIV had a negative impact on short-term CO_2 elimination compared with using a HH, particularly in patients with hypercapnia.
- The negative effects of using an HME during short-term NIV are probably a consequence of the increased deadspace contributed by the device.

DEFINITIONS:

Chronic obstructive pulmonary disease (COPD)	A progressive disease in which the small airways become narrowed, limiting airflow to and from the lungs and causing shortness of breath. In contrast to asthma, air flow limitation in COPD is poorly reversible
Deadspace	The space in the trachea, bronchi, and other air passages which contains air that does not reach the alveoli during respiration
Dyspnoea	Laboured breathing or shortness of breath
Fraction of inspired oxygen (FiO_2)	The fraction of oxygen in inspired gas
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
Heated humidifier (HH)	A device that actively adds heat and water vapour to inspired gas
Hypercapnia	The presence of an abnormally high level of carbon dioxide in the circulating blood
Hypoxia	Reduction of oxygen supply to tissue below physiological levels despite adequate perfusion of the tissue by blood
Intensive care unit (ICU)	A hospital facility providing intensive nursing and medical care for critically ill patients
Minute ventilation (VE)	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
Noninvasive ventilation (NIV)	The delivery of ventilatory support without the need for an invasive artificial airway
Partial pressure of arterial oxygen (PaO_2)	The part of total blood gas pressure exerted by oxygen gas; a measure of how much oxygen is dissolved in the blood and how well oxygen is able to move from the airspace of the lungs into the blood
Partial pressure of carbon dioxide (PCO_2)	The part of total blood gas pressure exerted by carbon dioxide gas; a measure of how much carbon dioxide is dissolved in the blood and how well carbon dioxide is able to move out of the body
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 (WOB)	The force required to expand the lung against its elastic properties

*in*Science Communications

F Lellouche, SM Maggiore, N Deye, S Taillé, J Pigeot, A Harf, L Brochard
Intensive Care Medicine 2002; 28:1582-1589

Effect of the humidification device on the work of breathing during noninvasive ventilation

AIM:
To compare the effects of humidity delivery using a heat and moisture exchanger (HME) and a heated humidifier (HH) on arterial blood gases and work of breathing (WOB) in hypercapnic patients undergoing noninvasive ventilation (NIV).

METHOD:
Patients (n = 9) were in the intensive care unit and were receiving NIV with pressure support for moderate to severe acute hypercapnic respiratory failure; 7 were having an acute exacerbation of chronic obstructive pulmonary disease. Arterial blood gases and WOB parameters were assessed at baseline and during the following five 20-min periods: small HME (Hygrobac-S; DAR) with zero end-expiratory pressure (ZEEP), standard HME (Hygrobac; DAR) with ZEEP, HME with 5cm H2O positive end-expiratory pressure (PEEP), HH (MR850; Fisher & Paykel) with ZEEP and HH with PEEP; patients spontaneously breathed low-flow nasal oxygen for 15-min between treatment periods, which were administered in a random order.

RESULTS:
At ZEEP, minute ventilation (MV) was significantly higher with the HME than with the HH (15.8 vs 12.8 L/min; p = 0.03), despite a slightly higher arterial carbon dioxide (CO_2) pressure and a lower pH. All indices of WOB were significantly higher in the HME versus HH group. In addition, NIV ventilation with an HME failed to reduce WOB compared with baseline, with a trend towards an increase (p = 0.06). The addition of PEEP significantly decreased WOB during the use of an HME. There were no changes in an index of patient effort during use of a HH, although there was a trend towards decreased patient effort when PEEP was added. Differences between the HH and HME groups during PEEP were similar to those during ZEEP, that is WOB was consistently and significantly higher in the HME group. There were no significant differences between the small HME and the standard HME, with the exception of expired tidal volume, which was significantly higher with the standard HME (p = 0.01).

DISCUSSION:
The increased VE and WOB seen with an HME in this study is similar to that observed in comparisons of HME and HH in intubated patients undergoing mechanical ventilation. The almost 2-fold increase in WOB with an HME versus HH at ZEEP is primarily attributable to the additional deadspace added by the HME. At ZEEP, use of an HME could completely counteract the beneficial effects of NIV.

CONCLUSION:
Use of an HME markedly increases WOB compared with use of a HH during NIV in patients with hypercapnic acute respiratory failure. Use of an HME in this setting means that the goals of NIV, namely increasing alveolar ventilation and reducing respiratory muscle work, may not be achieved.

KEY POINTS:

- Use of an HME in patients receiving NIV for moderate to severe hypercapnic respiratory failure markedly increases WOB.
- The efficacy of NIV is likely to be reduced when an HME is used in patients receiving NIV for moderate to severe hypercapnic respiratory failure.
- At ZEEP, use of an HME could totally counteract the beneficial effects of NIV.
- A HH should be used for humidification of inspired gases during NIV to ensure optimal efficacy.

DEFINITIONS:

Heated humidifier	A device that actively adds heat and water vapour to inspired gas
Heat and moisture exchanger (HME)	A passive humidification device that is designed to collect and store some of the exhaled heat and moisture from the patient's breath, and to deliver it to the inhaled gas during inspiration
Noninvasive ventilation (NIV)	The delivery of ventilatory support without the need for an invasive artificial airway
Work of breathing (WOB)	The force required to expand the lung against its elastic properties

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
Minute ventilation (MV)	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 volume in the trachea, bronchi, and other conducting airways (anatomical deadspace) as well as any enclosed space present between the patient and the ventilation circuit including face masks, HMEs etc. These areas contain air that does not reach the alveoli during respiration
Zero end expiratory Pressure (ZEEP)	The pressure in the airway is the same as atmospheric pressure at the end of the expiratory cycle during mechanical ventilation

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