

Essential Practices

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Humidification During Mechanical Ventilation: Current Trends and Controversies

Tim Op't Holt, EdD, R.R.T., AE-C, FAARC

Abstract

To aid respiratory care professionals in determining the most appropriate humidification device for mechanically ventilated patients, this article reviews humidification principles, standards regarding humidification devices, currently available humidification options, indications and contraindications for their use, and controversies related to optimum humidification. Heated pass-over and wick humidifiers, active heat and moisture exchangers (HMEs), and conventional heat and moisture exchangers (HMEs) are addressed. While the controversy regarding optimum humidity for the mechanically ventilated patient remains unresolved, a review of existing studies indicates that both heated humidifiers (HHs) and active HMEs can deliver fully saturated gas at body temperature, eliminating the humidity deficit. When used correctly and in the absence of contraindications, conventional HMEs may be used without complications and have been shown to result in cost savings and decreased personnel time. It is suggested that some HMEs may be used for up to seven days without changing, but in-vivo hygrometric testing is recommended before prolonged use. Neither active humidifiers nor HMEs are blamed for the incidence of ventilator-associated pneumonia (VAP). In some patient populations, such as patients being ventilated with permissive hypercapnia and patients with chronic ventilatory failure that are difficult to wean, a heated humidifier may be preferred.

Roundtable:

Selecting the Optimal Humidity for your Patients

Moderator: **Neil MacIntyre** MD, FAARC

Panelists: **Richard Branson** MS, RRT, FAARC • **Ray Ritz** BA, RRT, FAARC • **Richard Kallet** MSc, RRT, FAARC

Abstract

Physicians depend on the skill and experience of respiratory care professionals to ensure optimal heat and humidity are maintained for patients with artificial airways as some HMEs and HHs do not meet the minimum standard set by the AARC Clinical Practice Guideline on Humidification During Mechanical Ventilation. Due diligence must be exercised when basing a clinical decision on bench work as heat and humidity devices have been tested in non-clinical environments, though nothing in the published literature suggests heat and humidity needs are different because of the type of artificial airway used. Some HMEs have been tested and found effective for as long as seven days without being changed, however, long-term ventilation is best treated with heated humidification. In addition, patients with primary lung disease need more scrutiny of their heat and humidity needs compared to those with non-pulmonary infections. The four issues to keep in mind, related to heat and humidity strategy during mechanical ventilation, are efficacy, cost, practicality, and the reduction of VAP.

Humidification During Mechanical Ventilation: Current Trends and Controversies

Tim Op't Holt, EdD, R.R.T., AE-C, FAARC

Humidification during mechanical ventilation has evolved through many stages. Originally, clinicians derived the necessary moisture by heating a large quantity of water in two frying pans welded together. This was refined to ever more sophisticated equipment and techniques, such as the heating of a small quantity of water in a wick humidifier, passing water vapor through a heated wire ventilator circuit, and eventually the use of HMEs containing hydrophobic and hygroscopic filter media. In this article, we review current practices and controversies in the humidification of mechanically ventilated patients.

Humidification Principles and Terminology

During normal respiration, inspired gas is heated and humidified as it traverses through the upper airways. By the time the inspired gas reaches a point just below the carina, it has been heated to body temperature and saturated with water vapor, which equates to an absolute humidity of 44 mg H₂O per liter of gas. When the upper airway is bypassed during mechanical ventilation, inspired gas from the ventilator is no longer in direct contact with the heat and moisture normally supplied by the upper airway and a humidity deficit is created. The humidity deficit is the difference between the water vapor content of the inspired air from the mechanical ventilator and the humidity at body temperature, saturated. The purpose of a humidifier is to prevent or minimize the humidity deficit by providing an adequate supply of heat and moisture to the inspired gas before it reaches the patient's airway.

As referenced in the AARC Clinical Practice Guidelines, the American National Standards Institute (ANSI) recommends that humidifiers provide an output of at least 30 mg H₂O per liter at 30°C when the upper airway has been bypassed.¹ This recommendation is based on the premise that some heat and moisture exchange occurs on the inside of the endotracheal tube (ETT) and that the distal trachea beyond the tip of the ETT and the first few centimeters of the mainstem bronchi also contribute heat and water vapor to the inspired gas. The remaining 14 mg H₂O/L required to increase the humidity of the inspired gas from 30 mg H₂O/L to 44 mg H₂O/L must be provided by the mucosa.¹ The only place for the respiratory system to obtain this humidity is from lower in the airway. This deepens the isothermal saturation bound-

ary and may lead to inadequate humidification, inspissation of secretions, atelectasis, and infection. Recent literature and equipment manufacturers recommend that gas be delivered to the intubated patient at 37°C and 44 mg H₂O/L, which is fully saturated gas at body temperature. Humidifiers in the marketplace today can provide this level of humidification, if desired.

Humidifier Efficiency

Factors affecting humidifier efficiency include the water surface area and duration of exposure to gas as well as the temperatures of the reservoir and connective tubing (i.e., the ventilator circuit). Water surface area is increased by putting an insert in the humidifier upon which water particles may reside temporarily while gas blows past in a turbulent flow. Another method is to line the inner surface of the humidifier chamber with an absorbent paper "wick". Part of the wick is immersed in the humidifier reservoir and the humidifier chamber is surrounded by a heater. The wick absorbs water from the reservoir which, when heated, provides water vapor to the inspiratory gas as it circulates through the humidification chamber. Water content in the ventilator circuit is maintained by a heated wire. If the circuit temperature is maintained above the dew point, condensation will not occur, and the full water vapor complement is delivered to the airway.

The current cohort of HHs contain heated water within a plastic or metal chamber, absorbent paper wicks, and heated wires in both the inspiratory and expiratory limbs of the ventilator circuit. These humidifiers allow for adjustment of temperature at the patient from approximately 32-40°C, utilize automatic water feed systems, monitor temperature to prevent overheating and heater failure, and control the heated wire.

The presence of the heated wires decreases condensation, which when left uncontrolled can lead to lavage of the patient's airway, contamination of the circuit, excessive water consumption, and the need to drain the circuit. Correct use of the heated wire circuit minimizes this condensate.

Some ventilators heat the gas above ambient before it reaches the humidifier. Carter et al determined that the humidity output from a heated humidifier varies with the inlet gas temperature, and decreases as the inlet gas temperature increases.² In a study using a recent generation heated humidifier, absolute humidity output varied from 19-38 mg H₂O/L, with the tempera-

ture set at 37°C at the outlet of the humidifier chamber, and 40°C at the wye of the ventilator circuit.³ A high ambient air temperature and/or a high inlet gas temperature decreased heated humidifier performance, resulting in a delivered absolute humidity of <20 mg H₂O/L. When the inlet temperature was high, the heater shut off, water in the chamber cooled, and evaporation ceased. Another heated humidifier from the same manufacturer has incorporated a compensation function that may be used to increase the set temperature at the chamber outlet, resulting in an absolute humidity of > 30 mg H₂O/L, when ambient and chamber inlet temperatures are high. Low delivered absolute humidity may also be avoided by using a humidifier that allows the clinician to adjust and increase the humidifier outlet temperature and the desired patient airway temperature. However, this may lead to increased condensation in the circuit.

It appears from these two studies that if either ambient temperature or chamber inlet temperature is high, the humidity output from a non-compensating or non-adjustable heated humidifier is insufficient. A further problem is that if the ambient temperature is high, a fan is often used to cool the patient. Since the fan inevitably blows on the ventilator circuit as well as on the patient, this results in cooling of the circuit and increased condensate.

Heat and Moisture Exchangers

There are five types of HMEs: (1) the condenser humidifier, which is unsuitable for mechanical ventilation, (2) the hygroscopic condenser humidifier, (3) the hydrophobic condenser humidifier, (4) hygroscopic condenser humidifier filters, and (5) hydrophobic condenser humidifier filters. HMEs with appended bacterial/viral filters are also in use that provide both humidification and filtration of the respiratory gases. Some respiratory care departments use HMEs and combination HME/filters exclusively to provide humidification to mechanically ventilated patients. All HMEs utilize the same principles, some more efficiently than others. Heat and exhaled moisture are absorbed by the hygroscopic or hydrophobic material and stored until the following inhalation, when heat and moisture are imparted into the dry gas of the ensuing breath.

Each device has its own level of efficiency.⁴ In addition, HMEs are often tested under differing conditions, making it difficult to compare them either to each other or to HHs. Hygroscopic and hydrophobic filter humidifiers have been found to be more efficient than other HMEs, in terms of returning heat and moisture to the airways. Furthermore, another product utilizes an HME with a water infusion system and a heater jacket (Humid-Heat®, Louis Gibek AB, Upplands Vasby, Sweden). Its humidity output is increased by infusing water onto a wicking material in the HME and surrounding the HME with heat, thereby increasing the water carrying capacity of the gas. Inspired gas reaches 100% relative humidity (RH) at 37°C in this device, which is referred to as an active heat and moisture exchanger.⁵ 100% relative humidity means that the gas is saturated at that temperature.

How Much Humidity is Enough?

When humidifiers run too cold (i.e., <32°C), humidity can be reduced to the point where air-

way plugging is possible. Typically, humidification decreases as minute volume through the humidifier increases. Nishida et al found that the airway temperature setting affected the humidity of inspired gas at varied minute ventilations and I:E ratios.⁶ They observed that at 32°C, absolute humidity was <30 mg H₂O/L. Under these circumstances, it would be better to set the airway temperature to 37°C because at all minute volume and I:E conditions, humidity was > 30 mg H₂O/L. The authors concluded that the temperature of the airway should be maintained at 37°C, which is in conflict with the AARC Clinical Practice Guideline referred to above (i.e., Humidification During Mechanical Ventilation). While this controversy is yet to be resolved, keeping the airway temperature at 37°C is gaining support, as was seen in the Lelouche study.

In an industry-sponsored study, the airway workload required to condition gas to normal body temperature and saturation, as a component of work of breathing, was used as the end point.⁷ The authors stated that as the humidifier temperature and humidity decreased from 37°C and 44 mg H₂O/L, respectively, airway work load increased linearly and significantly. This shifts the isothermal saturation boundary further down the airway. In their review of the literature, they noted that delivery of < 100% RH gas to the end of the ETT will result in the drying of any pooled secretions and may lead to ETT occlusion, increased resistance to airflow, and atelectasis. They concluded that airway workload and water loss were “neutral” when inspired gas was delivered at body temperature and saturated.

One way of monitoring the adequacy of humidity in the airway is to use a portable bedside hygrometer. Fink, in his chapter in the 8th edition of *Egan's Fundamentals of Respiratory Care*, states that hygrometers should be as commonly used as the oxygen analyzer.⁸ In the absence of a hygrometer, he suggests that therapists adjust humidity so that a few drops of condensate are seen at the wye in the ventilator circuit. This is also an appropriate technique for HMEs. Other studies support the need for assessing the effectiveness of humidifiers by looking for moisture in the ventilator circuit and at the wye or between the HME and the ETT.⁹ HME efficiency tables, such as those in Egan's 8th edition, are out of date, so we must refer to recent literature for contemporary results.⁴ Branson et al summarize the advantages and disadvantages of contemporary humidifiers in Table 1.

What is the Appropriate Humidification Device for a Specific Clinical Situation?

There are three categories of humidifier: the heated water-filled humidifier with heated wires, the HME, and the active HME. What is the best device for a specific situation? If we use the AARC Clinical Practice Guidelines minimum delivery target of 30 mg H₂O/L, a properly functioning heated humidifier will deliver this humidity under all circumstances of tidal volume and disease state. But, because of the issues listed above, it may not always be the safest or most cost effective humidifier. The Clinical Practice Guidelines imply that unless specifically contraindicated, the HME will be acceptable. HMEs are contraindicated in patients with thick, copious or bloody secretions; an expired tidal volume of < 70% of inspired tidal volume (as

Table 1. Advantages and Disadvantages of Humidification Devices

	Advantages	Disadvantages
Heated Humidification with humidity heated wire circuit	Wide range of temperatures Universal application Reliable Temperature monitoring Alarms Elimination of condensate	Potential for reduced relative and airway obstruction Cost if used < 48 hours Lack of portability Complexity
HME	Passive operation Portable Lightweight Simple Low cost	Net water loss from respiratory tract Not suitable for all patients Dead space Resistance Potential for occlusion Must remove to administer
Active HME	Universal application Low water consumption Elimination of condensate Temperature monitoring Alarms Continued passive operation if electricity or water source is lost Elimination of water traps/heated wires	Dead space Weight Potential for occlusion Limited temperature range Heat source near patient Must remove to administer aerosols
<small>From: Branson RD, Campbell RS, Johannigman JA, Ottaway M, Davis K Jr., Luchette FA, Frame S. Comparison of conventional heated humidification with a new active hygroscopic heat and moisture exchanger in mechanically ventilated patients. <i>Respir Care</i> 1999;44(8):912-917.</small>		

seen in a bronchopleural fistula); a body temperature of < 32°C; and a spontaneous minute volume of > 10 L/minute.

According to Branson et al, the active HME overcomes problems associated with the heated humidifier and passive HME, and as a result may be universally applied.⁵ Consistent with the Clinical Practice Guidelines, Branson's guidance on humidifier selection rests on the patient's temperature, secretion quality, blood in the sputum, history of chronic lung disease and duration of ventilation. Some have opposed the idea of using the HME in patients with chronic obstructive pulmonary disease, (COPD) due to HME dead space and an increased work of breathing. This is discussed below, as is the use of an HME during permissive hypercapnia. No other specific recommendations were found based on patient type or disease that called for a particular humidifier.

Efficiency, Cost, and Nosocomial Infection

There have been a number of studies on efficiency, cost, and incidence of nosocomial infection when using HHs and HMEs. It is difficult to make definitive statements about these issues because there is little evidence, as noted by Bench.¹⁰ She found only two articles that met rigorous study criteria from among over 200 articles cited. One was a study by Kirton et al comparing HHs and HMEs.¹¹ An HME filter (hydrophilic/hydrophobic) was compared to a heated wire, water wick humidifier. In this prospective, randomized, non-blinded trial of 280 consecutive trauma patients, the authors found that HME use was associated with a significant reduction in late onset, hospital-acquired, VAP,

a significantly decreased number of ICU days, and a significantly reduced cost. In addition, there were no partial ETT occlusions with the HME.

In the study by Branson, a heated humidifier was compared with the active humidifier in 30 patients to determine humidification performance.⁵ The active humidifier provided similar humidification to the heated humidifier, but with significantly less water use and condensate. The dead space of the active HME was 73 mL, or 54 mL without the flex tube. This may have an adverse effect on patients with a pre-existing increase in dead space, or with difficulty weaning. The weight of the active HME is 79 g, twice that of conventional HMEs. However, the HME was held by the ventilator support arm or it rested on a towel on the patient's chest. If the patient were to produce a large amount of sputum, it would flow by gravity into the HME, potentially blocking it, and necessitating that the HME be changed.

Extended Use of the Same HME Beyond 24 Hours

Most commercially available HMEs recommend that they be changed every 24 hours. However, several published studies have addressed the viability of using the same HME on a single patient for longer than 24 hours before changing. Davis et al studied 220 patients receiving mechanical ventilation, and using a single HME for three days.¹² They concluded that in the absence of sputum contamination, the device did not provide a medium for bacteria to grow. While there was an increase in resistance in the hygroscopic and hydrophobic devices, it

was below the recommended maximum resistance of < 5 cm H₂O/L/sec. They also concluded that hygroscopic HMEs have superior heat and moisture exchanging capacities at a lower dead space than do hydrophobic devices. Both HMEs provided an absolute humidity of 27-32 mg H₂O/L.

Thomachot et al studied a group of 13 patients with no history of respiratory disease.¹³ The same hygroscopic HME was used for 96 hours with no adverse events, like ETT occlusion. Absolute humidity ranged from 32.4 to 33.1 mg H₂O/L across the four days of the study with the ventilator circuit remaining sterile. The resultant time and cost savings led to the use of HMEs for all patients, except those with COPD, since no conclusion could be inferred about patients who may have pulmonary disease.

These results were extended to one week by Ricard et al, without changing the HME.¹⁴ This group used a hygroscopic and hydrophobic HME to provide heat and humidity to a group of 33 patients, 10 of whom had COPD. The HME was kept suspended above the ETT to avoid accumulation of secretions. Absolute humidity throughout the week approximated 30 mg H₂O/L. In non-COPD patients, the absolute humidity was 30 to 31 mg H₂O/L, while in COPD patients, the absolute humidity was 29 to 30 mg H₂O/L. The values for absolute humidity were lower in the COPD patient group than in the rest of the study population with a significant difference during days three through six. As a result, the authors recommend that hygrometric measurements be taken when investigating HMEs and the HME should not be used on COPD patients, based on their lower absolute humidity, and anatomic and functional alterations in the bronchial epithelium. They concluded that HMEs can be used for longer than 24 hours, based on daily measurements of absolute humidity. Performance of HMEs in COPD patients varied (sometimes < 30 mg H₂O/L) so they concluded that HMEs should be used cautiously in patients with COPD.

Other studies investigated the use of the same HME for two to seven days and found similar results: little or no contamination of the ventilator circuit, no ETT occlusion, cost savings, and decreased personnel time.¹⁵⁻¹⁷ In Boyer's study, the HME was suspended above the patient to prevent secretion accumulation in the HME and closed suction catheters were not used. Since the closed suction catheter incorporates an elbow, it might be difficult to include a closed suction catheter in this particular setup.¹⁶

In a study by Thomashot, a hydrophobic HME was studied in 155 medical and trauma patients ventilated more than two days.¹⁷ In 84 patients, the HME was changed daily. In 71 patients, the HME was changed after seven days. The rate of VAP between the two groups was similar and costs were significantly less in the group using the same HME for seven days. There were no tracheal tube occlusions, tracheal instillations of saline were rare, and no patients needed to be switched to a heated humidifier. The authors emphasized the following points for HME use:

1. Patients with contraindications must be excluded (hypothermia, bronchopleural fistula).



Figure 1. Humid-Heat® Hudson RCI

2. Tube patency must be checked by repeated suctionings.
3. HMEs must be changed when they are visibly soiled.
4. HMEs should be placed vertically above the tracheal tube and the position repeatedly checked by nurses and doctors. (Note: this study was done in France where there are few respiratory therapists)

While there was tracheal colonization in both groups, this was attributed to aspiration, not the HME or the ventilator circuit. There were no differences in length of stay, ventilator days, or mortality.

Difficult to Wean Patients and Dead Space

Two studies have looked at the issue of dead space, one in patients with Acute Respiratory Syndrome (ARDS) who were ventilated first with an HME¹⁸ and then with a heated humidifier.¹⁹ In patients with ARDS, it may be better to use a heated humidifier when permissive hypercapnia is used to ventilate with a low tidal volume for lung protection. In a study of 11 ARDS patients, PaCO₂ decreased 11 ± 5 mm Hg when the 100 mL dead space HME was replaced by a HH. Ventilator parameters were maintained throughout. As the dead space was removed, alveolar ventilation improved. Therefore, in patients with ARDS undergoing permissive hypercapnia, it may be desirable to use a heated humidifier rather than an HME.¹⁸

Girault studied the effects of HMEs versus HHs in 11 patients with acute or chronic respiratory failure who failed a T-piece trial, and therefore were categorized as difficult to wean.¹⁹ The HME was a hygroscopic and hydrophobic device with 84 mL of dead space. The heated humidifier was a pass-over type with a heated wire circuit. All patients in these trials were ventilated with either 7 or 15 cm H₂O pressure support ventilation (PSV). Inspiratory effort for a given PSV level was significantly greater with the HME (as measured in terms of joules/liter joules/minute pressure-time product, diaphragmatic pressure, or esophageal pressure). Intrinsic positive end-expiratory-pressure (PEEP) was also higher with the HME. These differences were attributed to the increased dead space of the HME, as there was an increase in minute ventilation (V_E) to compensate for the HME. Other factors that may be responsible for the increased work are the resistance imposed by the HME and the increase in intrinsic PEEP. The au-

thors concluded that unless the PSV level is considerably increased, the use of this type of HME should not be recommended in difficult, or potentially difficult to wean, chronic respiratory failure patients.¹⁹

Conclusions

HHs and active HMEs can deliver fully saturated gas at body temperature, eliminating humidity deficit. Most HMEs deliver ≥ 30 mg H₂O/L, when used with the appropriate patient population, but do not reach body temperature and humidity levels. Most authors have concluded that the humidity provided by the HME is adequate as long as contraindications are not present. From these readings, the controversy about how much humidity is optimal seems unresolved, yet when used correctly, either the heated humidifier or HME may be used with no complications. Neither HHs nor HMEs are blamed for the incidence of VAP. The authors cited attribute VAP to aspiration from above the ETT cuff. Some HMEs may be used for up to seven days without any requirement to change them, but the authors cited caution that an HME should be hygrometrically tested in-vivo before prolonged use. HME use has resulted in considerable cost savings and decreased personnel time. In patients ventilated with permissive hypercapnia, the heated humidifier may be preferable, due to the dead space of the HME. In patients with chronic ventilatory failure who are difficult to wean, the heated humidifier may be preferred due to concerns about dead space, occlusion by secretions, and increased work of breathing.

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Roundtable: Selecting the Optimal Humidity for your Patients

Moderator: Neil MacIntyre MD, FAARC
Panelists: Richard Branson MS, RRT, FAARC
Ray Ritz BA, RRT, FAARC
Richard Kallet MSC, RRT, FAARC

MacIntyre: I would like to welcome everyone to the round table discussion on *Selecting the Optimal Humidification for Your Patient*. Let's get started with the first question.

In your opinion, what is the optimal heat and humidity for a patient with an artificial airway?

Ritz: Well from an ideal perspective, a humidifying device delivering 44 mg H₂O/L at 37° would be the gold standard. However, this is not a consistently achievable standard given uncontrolled environmental changes, and the presence of unheated portions of the breathing circuit between the end of the circuit wires and the patient. The AARC Clinical Practice Guideline on Humidification During Mechanical Ventilation calls for a minimum of 30 mg H₂O/L at 30° C. Even this standard is not consistently met under certain conditions by some heat and moisture exchangers and some HHs. Perhaps another definition of the optimal heat and humidity system is one that maintains an environment that prevents thickening of secretions, avoids airway occlusion, is comfortable for the patient, and limits injury to the airway mucosa. These are all difficult and subjective parameters to assess, and we depend on the skill and experience of the bedside clinicians to monitor our patients for any indication of inadequate humidification.

Branson: One way to look at it is that the optimal heat and humidity maximizes mucociliary function. The definition of optimal from a physiologic standpoint is difficult to pin down. Clearly, a wide range of heat and humidification values have been used without untoward effects.

Kallet: In the medical literature, the words, "adequate" and "optimal," are sometimes used interchangeably when discussing artificial heat and humidity therapy. This may be problematic as artificial humidification replaces the heating and humidifying functions of the upper airways bypassed during invasive mechanical ventilation. These anatomic structures heat the inspired gases to approximately 34°C with an absolute humidity of 40 mg/L. The lower respiratory tract provides the remaining heat and humidity, so that the inspired gases reaching the segmental bronchi are warmed to 37°C with an absolute humidity of 44 mg/L — a condition known as the isothermal saturation boundary. As the respiratory tract normally loses about 250 mL of water/day in heating and humidifying respired air, it is assumed that artificially heating and humidifying inspired gases to the same level provided by the upper airway adequately preserves the quality of normal secretions. Therefore, in

well-hydrated, mechanically ventilated patients with normal pulmonary functioning, optimal conditioning heats and humidifies inspired gases to 32 to 34°C at 100% relative humidity. This provides an absolute humidity of approximately 38 to 40 mg/L. In this situation, optimal conditioning should allow for normal insensible water loss from the body.

However, this recommendation may not be appropriate for patients with copious, thick secretions. It is assumed, but not proven, that systemic hydration is the most important factor in maintaining the appropriate viscosity of pulmonary secretions. If this is true, this assumption would also support optimal heat and humidity goals of approximately 34°C and 40 mg/L, respectively. Yet, the medical literature lacks any prospective randomized studies comparing the efficacy of systemic hydration — with normal heat and humidity conditioning of inspired gases, — to aggressive heat and humidification therapy in the presence of abnormal secretions. Therefore, optimal heat and humidification therapy in patients with abnormal secretions is unknown. Under these circumstances, optimal heat and humidity therapy should render pulmonary secretions that can be suctioned easily from the lungs, without the need for instillation of saline or supplementary aerosol therapy.

MacIntyre: Does it have to be normal?

Branson: As with "optimal heat and humidity," "normal" is difficult to define. The normal mechanism of humidification results in a net water loss from the respiratory tract. Under normal conditions, gas reaches the bifurcation at 32-34° C and near 100% relative humidity. I have always used these findings as the goal of humidification in intubated patients and, unfortunately, I don't know if normal is or is not optimal.

Kallet: If by normal, you mean that inspired gases should be delivered to the distal end of the artificial airway at ISB conditions, that is, 37°C and 44 mg/L absolute humidity, then the answer is no. What prospective clinical studies show is that HHs set to deliver inspired gas to the proximal airway, at a temperature between 34-36°C, provide sufficient heat and humidity therapy and prevent airway obstruction. Even a proximal airway temperature of 32°C was reported to provide sufficient heat and humidity. However, progressive narrowing of the ETT and a case of acute obstruction at this temperature also has been reported.

Ritz: Well, clearly there are hundreds of pa-

pers that have looked at the efficiency of various HHs and heat and moisture exchangers and shown that under various conditions the specific device being tested either worked well or did not work well. Many devices that did not provide "perfect" heat and humidity have been used successfully on numerous patients. Given that most mechanically ventilated patients are ventilated for less than two to three days and have normal ventilatory patterns, providing something close to 30 mg H₂O/L at 30° C may be fine.

MacIntyre: How strong is the evidence base?

Branson: The evidence for optimal humidification is poor. Most of our knowledge comes from animal studies performed in the 1960's.

Kallet: Although there have been more than 15 clinical studies on heat and humidification therapy during mechanical ventilation, none have directly tested whether systematically varying the level of gas conditioning from a relatively low setting of 32°C to a substantially higher level of between 38 and 39°C results in an optimal level of humidification, in patients with abnormal secretions, that is. I'm aware of only one large, prospective randomized trial that attempted to address this question. Interestingly, Branson et al reported that even when HHs were set to achieve a proximal airway temperature of between 34 and 36°C, clinicians continued to use saline lavage to clear secretions from the lungs, and the quality of the secretions remained relatively thick and tenacious.

Ritz: Many of the papers that review heat and humidity devices test them in non-clinical environments. In vitro tests may yield different results than in vivo tests, and we, as clinicians, must exercise due diligence when basing a clinical decision on bench work.

MacIntyre: Does artificial airway type matter? Is there a significant difference between "trach vs tube?"

Kallet: No. Both the endotracheal and tracheostomy tube bypass the upper airway and terminate in approximately the same location in the trachea, so the heat and humidity replacement needs should be the same. Nothing in the published literature suggests that heat and humidity needs are different because of the type of artificial airway used.

Branson: I agree. I do not believe that the goals of humidification change with the type of artificial airway. The real issues remain patient lung health, duration of ventilation, relationship of tidal volume to the device's dead space, and secretion quantity and quality.

Ritz: Both endotracheal and tracheostomy tubes bypass the upper airway so the humidification needs might appear to be the same, but the question is not that simple. For example, tracheostomy tubes can have either a single cannula or an additional inner cannula that can be removed for cleaning and to clear an obstruction. The presence of an inner cannula provides a much better margin of safety, if you choose to humidify with an HME. A tracheostomized patient may be mobile enough to travel about in a wheelchair and an HME is ideal for that appli-

caution. A speaking valve can be applied to a tracheostomy tube, however, this renders the HME useless since the valve diverts the exhaled gas through the upper airway and fails to re-charge the HME with heat and moisture.

MacIntyre: *Does duration of airway placement matter?*

Kallet: No. Although, well-hydrated adult patients who require long-term tracheostomy appear to tolerate minimal or no supplemental heat and humidity therapy well.

Ritz: The freshness of the airway may be less of an issue than other potential complications. Fresh bleeding into the airway obviously carries with it the increased risk of airway occlusion. Being aggressive at ensuring any potential clots are not inspissated is critical. When deciding on the optimal humidification system for long-term ventilation, there is some conflicting data. Some HMEs have been tested and found effective for as long as seven days without being changed. Many others have not. My sense is that a well-chosen HME may well be safe to use for 48 to 72 hours without changing, although this may be controversial. When it appears a patient is going to require prolonged mechanical ventilation, the use of a HH is indicated.

Branson: I agree with Ritz. I think that long-term ventilation is best treated with heated humidification. The fact that the patient requires long-term ventilation suggests a severity of illness that I believe is better suited to heated humidification. This includes elimination of the dead space of the HME, which facilitates low tidal volume ventilation and weaning with spontaneous breathing trials, and lower cost over several weeks of ventilation — assuming, that is, heated wire circuits are used, and the circuits are only changed between patients.

MacIntyre: *Does underlying disease matter?*

Kallet: Yes, it does. During mechanical ventilation, patients with primary lung disease need more scrutiny of their heat and humidity needs, as opposed to someone who requires mechanical ventilatory support for non-pulmonary reasons. For example, a surgical patient without pulmonary infection or trauma who is managed with a liberal fluid strategy will not have the same needs as a medical patient with COPD and congestive heart failure who is managed with fluid restriction and aggressive diuretic therapy. Branson et al found that, based upon the quality of the secretions, only 19% of mechanically-ventilated medical patients met indications for an HME compared to 67% of surgical patients.

Branson: I agree here too. The important issues are lung health, duration of ventilation, dead space issues, and secretion quantity and quality. As an example, an 80-year-old trauma patient with multiple fractures and injuries will require long term (> seven days) ventilation and may have difficulty during ventilator discontinuation. That patient would receive a HH right away. Using an HME and then switching to the HH, wastes money. For a 20-year-old with a single gunshot wound with an expectation of mechanical ventilation less than four days, I would choose an HME. Assuming, of course, that there

I think it is critical for the respiratory therapist to evaluate each patient and choose the right device right away.

are no other contraindications to HME use. A 55-year-old with a history of chronic bronchitis who produces a cup of mucus every morning, and requires mechanical ventilation for pneumonia would also receive an HH. I think it is critical for the respiratory therapist to evaluate each patient and choose the right device right away.

Ritz: The specific disease likely does not matter but the accompanying symptoms matter a great deal. The clinician must clearly understand the limitations, that is, tidal volume/minute ventilation ranges, dead space, and resistance of the HME they select. Ventilatory patterns that include large tidal volumes and/or minute ventilations will quickly render the HME ineffective, since it will have difficulty providing adequate heat and humidity. Small tidal volumes, (>300 cc) carry the risk of the patient re-breathing CO₂. Patients with limited ventilatory reserve that are undergoing weaning trials may find an HME increases the circuit dead space, which, in turn, increases their minute ventilation requirements and the HMEs inherent resistance could increase breathing.

Patients with air leaks, either through a chest tube or around their airway, are poor candidates for HMEs. Thick, copious, or bloody secretions are contraindications to the use of a HME. Hypothermic patients are perhaps better managed using an HH, not because it is effective at increasing core temperature, but because it may be more efficient at reducing further heat loss from the respiratory tract.

MacIntyre: *What are the challenges posed by the new generations of ventilators, if any?*

Ritz: One challenge for mechanical ventilators is to stay compatible with the new generations of HHs. As the HHs get more efficient, they are able to generate higher humidity levels, which is good for the patient. Unfortunately, these higher humidity levels can result in excessive rainout in the expiratory valve and flow sensor, if it is not adequately heated. I personally experienced loss of flow, volume monitoring, and annoying alarms as a new top of the line humidifier flooded my ventilator.

Although this next point is a bit off the target of humidity, providing effective bacterial and viral filtering of the ventilator exhaust is a significant

concern for staff in these days of SARS and bird flu.

Lastly, since any humidifier can deliver adequate humidity and, with a change in the room environment or patient breathing pattern, there can be a fall in the delivered humidity, a future improvement on all ventilators might be an independent humidity sensor.

Branson: I find the new ventilators are actually helping. We have seen that the type of humidifier can affect the accuracy of tidal volume monitoring, particularly when the volume is referenced to BTPS. Several new ventilators have a selection for humidifier type to account for these problems.

Kallet: I don't believe that ventilators per se are the issue, but rather the strategies used to manage patients. For example, appropriate heat and humidity therapy may be particularly important in patients with acute lung injury. This is because mucus plugging is a complication associated with both low tidal volume ventilation and high frequency oscillatory ventilation.

MacIntyre: *Is there anything new in the literature on how to choose one type of humidification device over another?*

Ritz: While not a new document, the AARC Clinical Practice Guideline on Humidification During Mechanical Ventilation is a valuable resource for all clinicians. Though it was published in 1992, it still offers excellent fundamental information on humidity standards. Several articles from the past few years do come to mind as excellent references: Rich Branson's evaluation of 21 HMEs (Respir Care 1996; 41:736-743) is a great reference if one is looking for bench data on humidity output, dead space, and resistance. Another is Lellouche's description of the effect of ambient temperature on the performance of heated wire humidifiers (Am J Respir Crit Care Med 2004; 170:1073-1079). It is very well done and points out a seldom appreciated characteristic of these devices, that is, because they may reduce the heater power to the humidifier reservoir, a high room temperature can result in reduced humidity to the patient. This paper also pointed out that some ventilators can heat up the inspiratory gas before it enters the humidifier, which can reduce the delivered humidity — the same as a high ambient room temperature. Clinicians should be aware that the combination of high ambient temperatures and a ventilator that develops a high output gas temperature may provide > 20 mg H₂O/L. They also point out that the presence of condensate in the HH chamber is not always a reliable indicator of the adequacy of humidification. This is an excellent read for anyone responsible for the operation of a heated wire circuit.

Branson: The most recent paper from the French group led by Brochard demonstrates that there is no difference in the VAP rate between HHs and HMEs. The selection is really a best fit proposition. For short-term ventilation of less than seven days, previously normal lungs, and normothermia, one should use an HME. For long-term support of more than seven days, low tidal volume ventilation, previous history of

secretion problems, frank blood or pulmonary edema, previous history of poor respiratory mechanics—such as COPD—and leaks around airways, one should use heated humidification.

Kallet: The four issues to keep in mind, related to heat and humidity strategy during mechanical ventilation, are efficacy, cost, practicality, and the reduction of VAP. For routine mechanical ventilation, the evidence from randomized clinical trials is clear that hygroscopic HMEs are an effective, cost efficient strategy to provide heat and humidity therapy during mechanical ventilation. However, HMEs also present five practical problems that require careful consideration. Firstly, the additional dead space may complicate using lung protective ventilation to manage patients with severe acute respiratory distress syndrome. Secondly, the increased circuit-related work of breathing for patients, both from the imposed resistance of the HME and also from the increased minute ventilation demand (secondary to the increased apparatus dead-space), which may complicate weaning them from mechanical ventilation. Thirdly, additional circuit breaks to remove and replace the HME, when in-line medication nebulization is used, may increase the risk of circuit contamination. The fourth problem is insufficient heat and humidity delivery in patients with copious, thick or bloody secretions. Lastly, the projected cost savings are diminished in patients who require both long-term mechanical ventilation and frequent HME replacement for filter obstruction.

The most recent meta-analysis found that the use of HMEs is associated with a reduction in VAP, particularly in patients ventilated for seven days or longer. However, these results are limited by the fact that many patients with common problems, such as tenacious secretions, obstructive lung disease, or hypothermia, often were excluded. In addition, VAP in many of these studies was diagnosed clinically and not confirmed by microbiological cultures. Moreover, a mere association between the decreased incidence of VAP and the use of HME may be more apparent than real. It is important to keep in mind that oral secretions contaminated with microbes from the gastrointestinal tract are the major source for VAP occurring after seven days.

Also, to prove that circuit contamination causes VAP requires rigorous, temporally appropriate microbiological surveillance. In other words, the identical pathogen must be isolated first, from circuit cultures, and then, from tracheal cultures. The majority of the studies examining the role of HMEs and HHs have not used rigorous infection monitoring to provide a definitive answer to this question. Interestingly, only clinical studies lacking microbiologic confirmation found that HMEs reduced the incidence of VAP, and even these results were not statistically significant.

MacIntyre: *Thank you, gentlemen. That concludes the round table.*

To summarize the discussion, there does not appear to be a consensus on the optimal heat and humidity for patients with an artificial airway. Each patient must be individually evaluated by the respiratory therapist. Though the AARC Clinical

Practice Guideline on Humidification During Mechanical Ventilation calls for a minimum of 30 mg H₂O/L at 30° C, many HMEs and HHs do not meet this standard under certain conditions. The important issues to consider are lung health, duration of ventilation, dead space issues, and secretion quantity and quality. Some studies have concluded that a HH may be more cost effective for patients with VAP who require long-term ventilation of more than seven days, while a HME best treats shorter-term ventilation requirements of less than seven days.

There was one comment that an independent humidity sensor could improve future ventilators, and in vitro tests might yield different results than in vivo tests when reviewing heat and humidity devices.

Thank you everyone for your participation.

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Questions

- According to the American National Standards Institute, how much humidity should a humidifier supply?
 - 44 mg H₂O/L at 37°C
 - 30 mg H₂O/L at 30°C
 - 24 mg H₂O/L at 37°C
 - 40 mg H₂O/L at 30°C
- What effect does a high ambient air temperature have on the humidity output of a heated humidifier?
 - the humidity output decreases
 - the humidity output increases
 - the humidity output is not effected by ambient temperature
 - the humidity output may increase or decrease
- How can the therapist determine the adequacy of humidity delivered to the patient's airway?
 - by watching for the presence of a few droplets of condensate at the airway
 - by using a hygrometer
 - by assuring that the temperature at the airway is 32-35°C
 - by keeping the reservoir of the humidifier at the recommended level
 - I, III only
 - II, IV only
 - I, II only
 - III, IV only
- What are the contraindications for the use of an HME?
 - presence of thick, copious secretions
 - bronchopleural fistula
 - hypothermia
 - patient has COPD
 - II, III, IV only
 - I, III, IV only
 - I, II, III only
 - I, III, IV only
- What conclusions have recent studies reached about the use of HMEs?
 - some HMEs may be used up to 15 days without a change
 - the use of HMEs has resulted in cost savings
 - the HME should be suspended above the ETT
 - the HME is effective for hydration of inspissated secretions
 - I, II only
 - II, III only
 - III, IV only
 - II, IV only
- What humidifier should probably be used during permissive hypercapnia in ARDS?
 - hygroscopic/hydrophobic
 - hydrophobic
 - hygroscopic
 - heated humidifier
- The main factor in deciding what type of humidifier to use in a patient with COPD is:
 - device dead space
 - control of condensate
 - type of filter on the HME
 - ability to control VAP
- The major factor causing VAP is:
 - the presence of a heated humidifier
 - condensate in the ventilator circuit
 - aspiration from above the ETT cuff
 - colonization of the HME filter
- The optimal heat and humidity system should include the following:
 - An environment that prevents thickening of secretions.
 - One that avoids airway occlusion.
 - One that is comfortable for the patient.
 - One that limits injury to the airway mucosa.
 - I,II only
 - I, IV only
 - III, IV only
 - all of the above
- The respiratory tract normally loses approximately how much water/day in heating and humidifying respired air?
 - 100 mL/day
 - 50 mL/day
 - 500 mL/day
 - 250 mL/day
- Under normal conditions, gas reaches the bifurcation at what conditions?
 - 32-34C and near 100% relative humidity
 - 32-34C and near 50% relative humidity
 - 35-37C and near 100% relative humidity
 - 35-37C and near 50% relative humidity
- The most important issues to consider regarding humidification change and the use of an artificial airway include?
 - patient lung health
 - duration of ventilation
 - relationship of tidal volume to the device's dead space
 - secretion quantity and quality
 - I, II only
 - II, III only
 - III, IV only
 - all of the above
- Based upon the quality of the secretions, Branson et al found what percent of mechanically-ventilated patients met indications for HME use?
 - 50%
 - 67%
 - 100%
 - 19%

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The goal of this program is to to educate the respiratory care professional on selection of the humidification option for the mechanically ventilated patient.

- What is the highest degree you have earned? Circle one.
1. Diploma 2. Associate 3. Bachelors
4. Masters 5. Doctorate
- Indicate to what degree you met the objectives of this program:
Using 1= Strongly agree to 6= Strongly disagree rating scale, please circle the number that best reflects the extent of your agreement to each statement:

Objectives

Upon completion of the course, the reader was able to:

- Describe the different types of HHs.
Strongly Agree Strongly Disagree
1 2 3 4 5 6
- List the consequences of inadequate humidification.
Strongly Agree Strongly Disagree
1 2 3 4 5 6
- Discuss the advantages and disadvantages of available humidifiers.
Strongly Agree Strongly Disagree
1 2 3 4 5 6
- List the contraindications for the use of the HME/humidification.
Strongly Agree Strongly Disagree
1 2 3 4 5 6

Please indicate your agreement with the following statement. "The content of this course was presented without bias of any commercial product or drug."

Strongly Agree Strongly Disagree
1 2 3 4 5 6

1	A	B	C	D	8	A	B	C	D
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2	A	B	C	D	9	A	B	C	D
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	A	B	C	D	10	A	B	C	D
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4	A	B	C	D	11	A	B	C	D
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5	A	B	C	D	12	A	B	C	D
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6	A	B	C	D	13	A	B	C	D
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	A	B	C	D					
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