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Humidification During Invasive and Noninvasive Ventilation

By Ruben Restrepo, MD, RRT, FAARC and Brian Walsh, RRT-NPS, ACCS, FAARC

Humidification of inspired gases is a standard of care for patients receiving mechanical ventilation. However, several challenges exist regarding optimal delivery of humidification in the ventilated patient that include the type of humidification device used and issues external to the humidifier's function. There are two broad categories of humidification used with mechanical ventilation; passive (unheated) and active (heated). Under normal conditions, most commonly available heated humidifiers (HH) follow the recommendations made by the AARC clinical practice guidelines. Ambient temperature, gas temperature (prior to the humidifier), the heater humidifier, the ventilator type, and the ventilator settings may adversely affect adequate warming and humidification of inspired gases. Continuous placement and removal of aerosol generators during mechanical ventilation and the effects that humidification and heat have on aerosol delivery are important considerations in the ICU setting. This review focuses on a number of frequently encountered situations that affect humidification in the clinical setting during the administration of invasive and noninvasive ventilation (NIV).

Panel Discussion: Humidification During Invasive and Noninvasive Ventilation

Moderator: Ruben Restrepo, MD, RRT, FAARC

Panelists: Robert Joyner, PhD, RRT, FAARC
Leo Wittnebel, PhD, RRT
Hui-Ling Lin, MSc, RRT, RN, FAARC

Humidification is an essential component of patient ventilation. In this panel discussion, 3 experts discuss themes related to optimal humidification, including optimal humidity for invasive vs noninvasive humidification, means to detect whether humidification is working, where to place the aerosol generator to minimize the effect on aerosol deposition, where within the circuit to monitor temperature, whether it is advantageous to have a humidifier that allows adjustments to absolute and relative humitidy, and other topics.

Humidification During Invasive And Noninvasive Ventilation

By Ruben Restrepo, MD, RRT, FAARC and Brian Walsh, RRT-NPS, ACCS, FAARC

Humidification of inspired gases is a standard of care for patients receiving mechanical ventilation. However, several challenges exist regarding optimal delivery of humidification in the ventilated patient that include the type of humidification device used and issues external to the humidifier's function. Inadequate humidification of medical gases could have very deleterious effects on airway mucosa.[1] There are two broad categories of humidification used with mechanical ventilation; passive (unheated) and active (heated). Under normal conditions, most commonly available heated humidifiers (HH) follow the recommendations made by the AARC clinical practice guidelines. They deliver absolute humidity (AH) that ranges from 33 mg H_2O/L to 44 mg H_2O/L at gas temperatures between 30°C and 37°C, respectively.[2, 3] Ambient temperature, gas temperature (prior to the humidifier), the heater humidifier, the ventilator type, and the ventilator settings may adversely affect adequate warming and humidification of inspired gases. Continuous placement and removal of aerosol generators during mechanical ventilation and the effects that humidification and heat have on aerosol delivery are important considerations in the ICU setting. This review focuses on a number of frequently encountered situations that affect humidification in the clinical setting during the administration of invasive and noninvasive ventilation (NIV).

Delivery Of Heated Humidification During Invasive Ventilation

Although HHs are considered the most efficient devices in providing the optimal conditions to the gas delivered to patients with an artificial airway,[4,5] undetected partial obstruction of the artificial airway may compromise the patient's ability to wean off of mechanical ventila-

First and foremost, it is very important to remember that heated humidifiers control temperature—not humidity levels.

tion.[6,7] Therefore, a good understanding of how HHs function and how they interact with different mechanical ventilators at different settings and clinical conditions is critical to those caring for patients receiving mechanical ventilation.

First and foremost, it is very important to remember that heated humidifiers control temperature—not humidity levels. Although gas at the ventilator inlet may range from 22°C to 26°C,[8] this temperature may increase depending on the type of ventilator used. However, the gas temperature drops as it travels through the inspiratory limb between the ventilator gas outlet and the heated humidifier inlet, also known as the dry part of the circuit. After gas enters the humidifier chamber, the heater warms to the preset humidifier chamber temperature. In the pass-over humidifier, the rate of evaporation and humidity output increase as water in the chamber increases in temperature. As more water vapor is produced, more energy from the heater is required to maintain the set temperature. A routine check of the heater humidifier and the breathing circuit may reveal visible signs of humidity production. The most common signs are the rate at which water is lost from the chamber and the amount

of condensation formed in the breathing circuit. A small amount of condensation or "rainout" in the circuit typically ensures proper humidifier function while excessive condensation may indicate that a decrease in the temperature may be required. Heated wires are used to ensure a temperature gradient of 1°C to 3°C between the water source and the patient Y to reduce cooling of the gases and therefore condensation.

Ambient Temperature.

High ambient temperature influences HH performance.[9] Inadequate air conditioning, burn units, neonatal units[10] or warm conditions proximal to the humidifier can increase ambient air temperature. When ambient air temperatures exceed 30°C, a greater reduction in humidity levels would be expected as the increased inlet temperature stops the heater plate from warming the water inside the chamber. Similar conditions are seen during winter months when heated rooms may create higher-than-normal temperatures. During summer months excessive cooling from air-conditioning outlets affects the gas temperature as it travels through the humidifier and the breathing circuit. Because a considerable amount of condensate may form, clinicians must exert extreme caution to avoid lavaging the patient's airway as water accumulates in the breathing circuit near the endotracheal tube. If the room temperature cannot be changed, it may be necessary to lower the temperature setting to avoid uncontrollable water condensation in the breathing circuit or increase the temperature gradient between the HH and the circuit. However, careful monitoring for signs of inadequate humidification must take place.

Impact of Gas Chamber Temperature.

A key element of proper humidifier functioning is the inlet chamber gas temperature. If it is very high, the heater may simply stop warming up without major generation of kinetic energy as the preset temperature is reached, since there is a strong inverse correlation between the inlet chamber temperature and heater temperature.[9] Higher gas inlet temperatures may be associated with an evident decrease in humidity production, from approximately 36 mg H_2O/L at a humidifier inlet gas temperature of 18°C (82% relative humidity at 37°C) to 26 mg H_2O/L

at a humidifier inlet gas temperature of 32°C (59% relative humidity at 37°C).[8] These humidity changes visibly translate to the amount of condensate present in the breathing circuit. On average, at a setting of 37 ± 2°C at the patient Y adapter approximately 14 g of condensate forms in the breathing circuit over 4 hours. At 40 ± 3° the amount of condensate dramatically drops to 3 g.[8] Even under the best ambient conditions and after following manufacturers' recommendations regarding temperature settings, AH may range from 19 mg H_2O/L to 36 mg H_2O/L.[9] Under constant flow conditions, the presence of inlet gas temperatures >26°C may be associated with humidity levels <30 mg H_2O/L (68% RH at 37°C), which does not meet the recommended level of humidification for mechanically ventilated patients.[11]

Impact of Ventilator Outlet Gas Temperature.

It is well known that some mechanical ventilators utilized within the ICUs warm inlet oxygen and air.[8,9] The high speeds of turbine or blower-powered ventilators generate the highest outlet temperatures. This effect can be confirmed by measuring the mean change in temperature between the ventilator's gas inlet and outlet. This temperature gradient could be as low as 1.7°C or as high as 7.9°C. These temperature gradients may create inlet chamber temperatures between 27.4°C and 29.8°C when ventilators run under normal ambient air temperature (23°C) and low minute volumes (10 L/min), and temperatures between 33.4°C and 37.9°C when ambient temperature is high (29°C) and minute volumes are high (20 L/min).[9] When using a ventilator with a high gas outlet temperature, keep the following in mind: when the chamber's water loss rate is higher than expected and less condensation is formed in the breathing circuit, extending the length of the inspiratory tubing prior to the heating chamber may offset the high temperatures at the gas outlet and allow the temperatures at the humidifier inlet to reach a lower level.

Impact of Ventilator Settings.

As the mechanical load increases, the operating temperature of most flow engines increase. High VE reduces the time gas stays in the water reservoir, thus significantly decreasing HH performance.[12]

Aerosol administration may require interruptions in mechanical ventilation that are detrimental to the patient.

Volumes derived from adding the inspiratory circuit plus the chamber or column of the humidifier plus the water added to the humidifier vary considerably among humidification devices. If the gas in the inspiratory circuit is saturated with vapor during the expiratory phase, inhaled gas may be humidified sufficiently even at high inspiratory flow. Increasing the tidal volume forces more dry gas to pass through the humidifying chamber or column.[13]

Humidification And Aerosol Delivery

The effects of humidification on aerosol delivery and lung deposition may differ according to the type of system used, dose and its placement in the circuit. Aerosol administration may require interruptions in mechanical ventilation that are detrimental to the patient. To ensure circuit integrity over the course of the prescribed aerosol therapy, a one-way valved T-piece adapter or a pMDI spacer are routinely left in the circuit. However, moisture generated from HH has a tendency to accumulate in the spacer as it mimics the function of a water trap. Accumulation can be as high as 5 mL after just few hours.[14] The presence of high relative humidity and temperature within the ventilator circuit is associated with 40 to 50% reductions in lung deposition with *in vitro* adult models[15-19] and up to 85% with *in vitro* pediatric models.[20-22] This massive reduction in aerosol delivery has prompted clinicians to routinely turn the HH off before administering the aerosol treatment. Since turning the heater off prior to aerosol treatment does not result in greater aerosol drug delivery, this practice should be abandoned.[23,24,26] The positive effect of a higher gas temperature on aerosol efficiency is countered by the more drastic effects of increased water vapor in the delivered gas.[25,26] As temperature and humidity may not be routinely separated to improve aerosol drug delivery, correct dosing (2-3 times higher than normal) and placement of the aerosol generator can be more efficient than any changes made on the humidification device to simulate normal ambient humidity conditions.[25]

Aerosol delivery efficiency also depends on the aerosol generator device placement in humidified and nonhumidified ventilator circuits. Placing a spacer 15 cm from the Y piece of a vibrating-mesh nebulizer, ultrasonic nebulizer, and pMDI Y piece is associated with the highest aerosol delivery efficiency under dry ambient conditions (25–27°C and <10% RH). The jet nebulizer may be most efficient when placed 15 cm from the ventilator outlet of both humidified and non-humidified ventilator circuits. Incorporation of heated wires prevents placement of aerosol devices halfway between the humidifier and the Y piece, as advocated in the past. If a jet nebulizer is placed at the humidifier outlet chamber, the introduction of cold gas may cause humidifier overheating, because the temperature registered at the thermistor will be lower and the heating element will add more energy to keep the set temperature. Placement of the nebulizer at the inlet of the HH chamber will prevent overheating, as the aerosol and gas from the ventilator are heated before exiting the humidifier and potentially improve drug deposition.

While HMEs have become routine practice in many ICUs, they are contraindicated when routine aerosol therapy is required during mechanical ventilation.[11] Placing the aerosol generator between the HME and the Y piece is a common practice to administer aerosolized treatments to patients receiving mechanical ventilation that may be associated with up to 35% greater airway resistance.[27] When HMEs become saturated with humidity from the patient and drug, resistance may potentially increase to the point of affecting patient-ventilator synchrony and the weaning process. In response to these concerns, manufacturers have designed HMEs that allow aerosol bypass by simply rotating a collar or valve on the device—without transferring rotational movement to the corrugated tubing of the ventilator circuit attached to the HME.

Humidification During Noninvasive Ventilation

In both acute and chronic care settings, noninvasive ventilation (NIV) is efficacious in treating a variety of diseases including chronic obstructive pulmonary disease (COPD), pulmonary edema, and obstructive sleep apnea.[28,29] Defined as the application of assisted positive pressure breaths without the use of an artificial airway (such as an endotracheal or tracheostomy tube), NIV has proven clinical utility both as a first-line treatment and as an alternative to conventional invasive mechanical ventilation.[30] Although invasive mechanical ventilation may be lifesaving, it also carries several potentially deleterious consequences, including nosocomial pneumonia, airway trauma, and increased need for sedation. In addition to avoiding these complications, NIV offers the advantages of preserving natural airway defense mechanisms, speech, and swallowing capability. In addition, the selections of an appropriate patient interface, adequate ventilator settings, and optimal humidification are critical to the success of NIV.[31]

Short-term NIV use is typically limited to the acute care setting for treating disease processes including COPD exacerbations, cardiogenic pulmonary edema, hypoxemic respiratory failure, and postoperative respiratory failure. The main goal is to avoid endotracheal intubation or reintubation.[32,33] Recommendations vary as to whether or not humidification is absolutely necessary. Quite often the need for humidification is associated with the length of time the patient is expected to be on NIV, the nature of the underlying disease, and patient tolerance. Because NIV is commonly administered via oral or nasal mask, the upper airway theoretically is still capable of warming and humidifying delivered gas to acceptable levels. Despite this, NIV may deliver air at a rate far in excess of normal physiologic inspiratory flow, compromising the airway's ability to adequately humidify the delivered gas. Heated humidification improves patient comfort and avoids some of the potential complications associated with breathing inadequately humidified gas, such as impaired mucocilary function and airway mucosa inflammation.[29, 34-36] The most common complaint during NIV is nose, mouth or throat dryness; thus, NIV without supplemental humidification may adversely affect patient comfort, potentially

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causing inspissation, subsequent retention of secretions, and increased airway resistance. In an acute event, these changes may be very deleterious for the patient.[37] Recent studies indicate that devices commonly used to administer NIV operating from a piped-in wall medical gas system deliver medical gas at a humidity level of 5 mg H_2O/L—far below that of ambient air. This is a significant deficit for the natural upper airway to overcome alone.[38] When patient intolerance and discomfort

with NIV prompt consideration of invasive ventilation, it seems counterintuitive that adequate humidification during NIV administration would increase the likelihood of patient tolerance and avert proceeding to invasive mechanical ventilation.

Despite the success of NIV in treating obstructive sleep apnea (OSA), patient compliance remains the biggest obstacle to treatment. Thirty to 66% of the patients with OSA complain of oral, nasal, and throat dryness that greatly contribute to the estimated 40% noncompliance rate.[29,37-40] Other common complaints include nasal congestion, claustrophobia, and pressure ulceration. In response to these common complaints, most manufacturers of NIV machines that are designed for domiciliary treatment of OSA include an integrated heated humidification system in their units. This humidification system compensates for the unidirectional airflow that occurs in the presence of leaks that are responsible for drying the nasal and oral mucosa. In addition, this flow also stimulates local nerves and releases inflammatory mediator cells, further complicating breathing for these patients.[37] Administration of heated humidification during NIV is associated with increased patient satisfaction and compliance and decreased prehumidification symptoms.[37,39]

Active Humidification and NIV. The benefits of humidification during NIV are clear. A plethora of heated humidifiers are available on the market, all capable of being utilized with invasive and NIV machines; and all have the advantage of being able to maintain a relatively constant tem-

Heated humidifier in use for a patient on high flow nasal cannula therapy

perature and humidity over a wide range of flows.[41] Recommendations for minimum acceptable levels at the nose and mouth during NIV range from 20 to 22°C with a relative humidity (RH) of 50% and an AH of 10 mg H_2O/L, with patient comfort being achieved typically at temperatures of 25–30°C and an AH of at least 15 mg H_2O/L.[33,38] Studies have shown that, without humidification, AH in NIV can be as low as 5 mg H_2O/L. Although implications for this low AH level during short-term NIV use are yet to be studied, AH data provide compelling evidence regarding the need for supplemental humidification, particularly when the duration of NIV use is unpredictable.[42] In regard to ventilator parameters, any manipulation of flow can change the efficiency of the humidifier. Interestingly, when heated humidification is added to the system, RH continues to be influenced by inspiratory positive airway pressure (IPAP) changes, despite substantial increases in RH delivered during NIV.[35] Implications of these findings mean that, in particular, patients requiring higher levels of IPAP during NIV would benefit from the addition of heated humidification to the system; and the highest available tolerable heater setting would provide the most adequate humidification in the face of uncontrollable ambient temperatures. Adjusting the patient airway temperature (which impacts AH) and temperature gradient between the HH outlet and the patient (which influences RH) can address changing humidification needs while enhancing patient comfort and tolerance.

Passive Humidification and NIV.

A passive humidification strategy consists of the use of a variety of devices, known as heat-and-moisture exchangers (HMEs) or artificial noses, designed to trap and recycle the patient's own heat and moisture upon exhalation and utilize it on subsequent inhalation. Their benefits include their low cost, the ability to provide adequate humidification under certain circumstances, and utility with certain patient populations.[43] Some clinicians limit their use strictly to postoperative patients, while others use them across the board for all invasively ventilated patients.[44] Although HMEs are seemingly redundant considering the single-limb circuit design of modern-day NIV machines and the need for the HME to serve as a conduit for both inspiration and ex-

> Patients requiring higher levels of IPAP during NIV would benefit from the addition of heated humidification to the system.

piration, several studies have investigated the possibility of HMEs as a low-cost alternative to active humidification. Lellouche et al.[38] compared the use of heated humidification, HME, and no humidification during NIV on healthy volunteers. Considering the unidirectional flow inherent in a single-limb circuit, the results were surprising: under relatively normal breathing conditions, the HME provided close to 30 mg H_2O/L in the absence of significant leak. However, that value declined 30% in the presence of a mask leak, which is a common occurrence during NIV administration. Even when the presence of leaks resulted in AH levels of 15 mg H_2O/L, no differences in patient tolerance were detected. When delivering NIV with no humidification, the absolute humidity of the anhydrous medical gas was only 5 mg H_2O/L, resulting in significant reduction in patient tolerance.[38] It is important to remember that this study utilized healthy test subjects and examined subjective comfort levels, as opposed to

Heat and Moisture Exchanger in use for patient during mechanical ventilation

the airway concerns particularly valid to treating patients with pulmonary disease.

Conclusions And Recommendations

Humidification devices that can control the humidifier outlet independent of ambient air temperature, ventilator gas output, or ventilator settings appear to be the logical approach to optimizing humidifier function. An adequate temperature gradient between the humidifier inlet temperature and the set patient temperature is conducive to generating the right amount of water vapor to meet the minimum recommended levels of humidity. Performance of heated humidifiers can be affected greatly by numerous conditions external to the humidifier's function.

Substantial evidence supports the dramatic reduction of aerosol delivery in humidified conditions. Thus, conditions that facilitate the accumulation of condensate in the ventilator circuit and the spacer may adversely affect aerosol lung delivery and patients' clinical response to aerosol therapy. When using passive humidification on patients requiring frequent aerosol treatments, it is imperative that the HME is equipped with a "bypass" option to optimize aerosol drug delivery and avoid the potential for increased airway resistance associated with a saturated HME.

The AARC has made the following recommendations:

1. Humidification is recommended on every patient receiving invasive mechanical ventilation.
2. When providing active humidification to patients who are invasively ventilated, it is suggested that the device provide a humidity level between 33 mg H_2O/L and 44 mg H_2O/L and gas temperature between 34°C and 41°C at the circuit Y-piece, with a relative humidity of 100%.
3. When providing humidification to patients with low tidal volumes, such as when lung-protective ventilation strategies are used, HMEs are not recommended because they contribute additional dead space, which can increase the ventilation requirement and $PaCO_2$.
4. It is suggested that HMEs are not used as a prevention strategy for ventilator-associated pneumonia.
5. Noninvasive active humidification is suggested for noninvasive mechanical ventilation, as it may improve ad-

herence and comfort.

6. Passive humidification is not recommended for noninvasive mechanical ventilation.

References

1. Williams R, Rankin N, Smith T, Galler D, Seakins P. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. Crit Care Med. 1996;24:1920–1929.

2. Restrepo RD, Walsh BK. AARC clinical practice guideline: humidification during mechanical ventilation: American Association for Respiratory Care. Respir Care. 2012:57:782–8.

3. Williams RB. The effects of excessive humidity. Respir Care Clin N Am. 1998;4(2):215-28.

4. Ricard JD, Markowicz P, Djedaini K, Mier L, Coste F, Dreyfuss D. Bedside evaluation of efficient airway humidification during mechanical ventilation of the critically ill. Chest. 1999;115:1646–1652.

5. Diehl JL, El Atrous S, Touchard D, Lemaire F, Brochard L. Changes in the work of breathing induced by tracheotomy in ventilator-dependent patients. Am J Respir Crit Care Med. 1999;159:383–388.

6. Heyer L, Louis B, Isabey D, et al. Noninvasive estimate of work of breathing due to the endotracheal tube. Anesthesiology. 1996;85:1324–1333.

7. Lacherade JC, Auburtin M, Soufir L, et al. Ventilator associated pneumonia: effects of heat and moisture exchangers and heated water humidificators [abstract]. Intensive Care Med. 2002;28:A507.

8. Carter BG, Whittington N, Hochmann M, Osborne A. The effect of inlet gas temperatures on heated humidifier performance. J Aerosol Med. 2002;15:7–13.

9. Lellouche L, Taillé S, Maggiore SM, et al. Influence of ambient air and ventilator output temperature on performances of heated-wire humidifiers. Am J Respir Crit Care Med. 2004;1073-1079.

10. Todd DA, Boyd J, Lloyd J, John E. Inspired gas humidity during mechanical ventilation: effects of humidification chamber, airway temperature probe position and environmental conditions. J Paediatr Child Health. 2001;37(5):489-94.

11. AARC Clinical Practice Guidelines: Humidification during Mechanical Ventilation. Respir Care. 1992(8);37:887–890.

12. Nishida T, Nishimura M, Fujino Y, Mashimo T. Performance of heated humidifiers with a heated wire according to ventilatory settings. J Aerosol Med. 2001;14(1):43-51.

13. Gilmour IJ, Boyle MJ, Rozenberg A, Palahniuk RJ. The effect of heated wire circuits on humidification of inspired gases. Anesth Analg. 1994;79:160–164.

14. Waugh JB, Waugh JB. Water accumulation in metered dose inhaler spacers under normal mechanical ventilation conditions. Heart Lung. 2000;29(6):424-428.

15. Fink JB, Dhand R, Grychowski J, Faney PJ, Tobin MJ. Reconciling in vitro and in vivo measurement of aerosol delivery from a metered-dose inhaler during mechanical ventilation and defining efficiency enhancing factors. Am J Respir Crit Care Med. 1999;159(1):63-68.

16. Dhand R, Jubran A, Tobin MJ. Bronchodilator delivery by metered dose inhaler in ventilator-supported patients. Am J Respir Crit Care Med. 1995;151(6):1827-1833.

17. Thomas SH, O'Doherty MJ, Page CJ, Treacher DF, Nunan TO. Delivery of ultrasonic nebulized aerosols to a lung model during mechanical ventilation. Am Rev Respir Dis. 1993;148(4 Pt 1):872-77.

18. Diot P, Morra L, Smaldone G. Albuterol delivery in a model of mechanical ventilation: comparison of metered-dose inhaler and nebulizer efficiency. Am J Respir Crit Care Med. 1995;152(4 Pt 1):1391-1394.

19. Fink JB, Dhand R, Duarte AG, Jenne JW, Tobin MJ. Aerosol delivery from a metered-dose inhaler during mechanical ventilation. An in-vitro model. Am J Respir Crit Care Med. 1996;154(2):382-387.

20. Wildhaber JH, Hayden MJ, Dore ND, Devadason SG, LeSouëf PN. Salbutamol delivery from a hydrofluoralkane pressurized metered-dose inhaler in pediatric ventilator circuits: an in vitro study. Chest. 1998;113:186-191.

21. Garner SS, Wiest DB, Bradley JW. Albuterol delivery by metered-dose inhaler with a pediatric mechanical ventilatory circuit model. Pharmacotherapy. 1994;14:210-214.

22. Lange C, Finlay W. Overcoming the adverse effect of humidity in aerosol delivery via pressured metered-dose inhalers during mechanical ventilation. Am J Respir Crit Care Med. 2000;161(5):1614-1618.

23. Lin HL, Fink JB, Zhou Y, Cheng YS. Influence of moisture accumulation in inline spacer on delivery of aerosol using metered-dose inhaler during mechanical ventilation. Respir Care. 2009;54(10):1336-41.

24. Kim CS, Trujillo D, Sackner MA. Size aspects of metered-dose inhaler aerosols. Am Rev Respir Dis. 1985;132(1):137-142.

25. Dhand R, Tobin MJ. Bronchodilator delivery with metered-dose inhalers in mechanically-ventilated patients. Eur Respir J. 1996; 9(3):585-595.

26. Farr SJ, Kellaway IW, Carman-Meakin B. Assessing the potential of aerosol-generated liposomes from pressurised pack formulations. J Contr Rel. 1987;5:119-127.

27. Hart MT, Ari A, Harwood R, Goodfellow L, Shear M, Fink JB. The effects of aerosol drug delivery on airway resistance through heat-moisture exchangers. (Author's thesis 2009.)

28. Meduri GU, Turner R, Abou-Shala R, Wunderink R, Tolley E. Noninvasive positive pressure ventilation via face mask: First-line intervention in patients with acute hypercapnic and hypoxemic respiratory failure. Chest. 1996;109:179-193.

29. Kakkar RK, Berry RB. Positive airway pressure treatment for obstructive sleep apnea. Chest. 2007;132:1057-1072.

30. Jaber S, Michelet P, Chanques G. Role of non-invasive ventilation in the perioperative period. Best Pract Res Clin Anaesthesiol. 2010;24:253-265.

31. Antonelli M, Pennisi G, Conti G. New advances in the use of noninvasive ventilation for acute hypoxemic respiratory failure. Eur Respir J Suppl. 2003;22:65s-71s.

32. Branson RD, Gentile MA. Is Humidification always necessary in the hospital? Respir Care. 2010;55(2):209-216.

33. Kacmarek R. Noninvasive positive pressure ventilation. Egan's Fundamentals of Respiratory Care. 9th ed. St. Louis, MO: Mosby Elsevier; 2009:1091-1114.

34. Wiest GH, Lehnert G, Bruck WM, Meyer M, Hahn EG, Ficker JH. A heated humidifier reduces upper airway dryness during continuous positive airway pressure therapy. Resp Med, 1999; 93; 21-26.

35. Holland AE, Denehy L, Buchan CA, Wilson JW. Efficacy of a heated passover humidifier during non-invasive ventilation: a bench study. Respir Care. 2007;52(1):38-44.

36. Chiumello D, Chierichetti M, Tallerini F, et al. Effect of a heated humidifier during continuous positive airway pressure delivered by a helmet. Crit Care. 2008; 12(2):R55.

37. Massie C, Hart R, Peralez K, Richards G. Effects of humidification on nasal symptoms and compliance in sleep apnea patients using continuous positive airway pressure. Chest. 1999; 116:403-408.

38. Lellouche F, Maggior SM, Lyazidi A, Deye N, Taillé S, Brochard L. Water content of delivered gases during non-invasive ventilation in healthy subjects. Intensive Care Med. 2009;35:987-985.

39. Mehta S, Hill NS. Noninvasive ventilation. Am J Respir Crit Care Med. 2001;163:540-577.

40. Ortolano GA, Schaffer J, McAlister MB, et al. Filters reduce the risk of bacterial transmission from contaminated heated humidifiers used with CPAP for obstructive sleep apnea. J Clin Sleep Med. 2007;3(7):700-705.

41. Schuman S, Stahl CA, Möller K, Priebe HJ, Guttmann J. Moisturizing and mechanical characteristics of a new counter flow type heated humidifier. Br J Anesthes. 2007;98(4):531-538.

42. Esquinas A, Nava S, Scala R, Carillo A, Gonzalez Diaz G, et al. Intubation in failure of noninvasive mechanical ventilation: preliminary results [abstract]. Am J Respir Crit Care Med. 2008;177:A64.

43. Pelosi P, Severgnini P, Selmo G, et al. In vitro evaluation of an active heat-and-moisture exchanger: The Hygrovent Gold. Respir Care. 2010; 55(4):460-467.

44. Riccard JD, Markowicz P, Djedaini K, Mier L, Coste F, Dreyfuss D. Bedside evaluation of efficient airway humidification during mechanical ventilation of the critically ill. Chest. 1999;115:1646-1652.

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Panel Discussion

Panel Discussion: *Humidification During Invasive and Noninvasive Ventilation*

Moderator: **Ruben Restrepo,** *MD, RRT, FAARC*

Panelists: **Robert Joyner,** *PhD, RRT, FAARC*
Leo Wittnebel, *PhD, RRT*
Hui-Ling Lin, *MSc, RRT, RN, FAARC*

What would you consider optimal humidity for patients undergoing invasive and noninvasive ventilation?

Joyner: Optimal humidity would provide sufficient heat and humidity to reestablish or maintain mucus to its ideal state of viscosity and promote its homeostatic function. This would "position" mucus to work optimally with the components of the mucociliary escalator. Invasive ventilation would normally require more heat and water to meet the demand created by bypassing the airway when compared to noninvasive ventilation, but physiological components of proper mucus function do exist outside of the airway and must also be managed (e.g. hydration status of the patient).

Lin: Physiologically, as indoor air passes through the nose and upper airway, it is warmed and moistened to 44 mg H_2O/L of absolute humidity at the carina[1]. When a patient is intubated, the natural mechanism of humidifying gas is bypassed. Inadequate airway humidification can result in a series of issues, such as atelectasis and increased airway resistance, resulting an increased work of breathing. Optimal humidity to an intubated patient undergoing mechanical ventilation provides an absolute humidity >33 mg H_2O/L[2]. Yet, providing humidity to a patient with noninvasive ventilation (NIV) remains controversial, since delivered gas

> Devices that provide as close to physiologic normal as possible are going to result in fewer complications due to therapy.
>
> - Wittnebel -

passes through the upper airways and is exposed to the normal humidifying system of the body. However, providing heated humidification is suggested for the patient's comfort when they are receiving cool, anhydrous gas from compressed air and liquid oxygen systems. The use of a heat and moisture exchanger should be avoided due to increased resistance and dead space when undergoing noninvasive mechanical ventilation.[3]

Wittnebel: One could argue that optimal humidification levels for patients remain the same, regardless of the selection of invasive or noninvasive ventilation; and in fact the American Association for Respiratory Care (AARC) clearly advocates for the practice.[2] In either instance, you are essentially providing cool, anhydrous medical gas to the patient. In doing so, the isothermic saturation boundary is essentially shifted deeper into the lungs, making it difficult to maintain the normal physiologic function of the airway and causing patient discomfort.[4] Methods that maintain or come closest to maintaining the normal position of the isothermic saturation boundary 5 cm below the carina are going to have the least negative impact on airway characteristics such as ciliary motility and secretion clearance. Devices that provide as close to physiologic normal as possible are going to result in fewer complications due to therapy. Consider that most abnormal pulmonary pathologies are associated with abnormal secretion characteristics and/or difficulty with airway clearance, even in spontaneously breathing patients. Now, couple that with the need to provide assisted ventilation, and peripheral issues such as patient comfort and compliance to therapy during an exacerbation and the role of adequate humidification becomes more important.[4,5] The AARC currently advocates for the use of active humidification for invasively ventilated patients at a level between 33 mg H_2O/L and 44 mg H_2O/L, measured at the ventilator circuit Y-piece with a relative humidity of 100%. Their recommendations for passive strategies such as the use of hygroscopic heat moisture exchangers (HMEs) include heat devices capable of providing at 30 mg H_2O/L.[2]

How should the RT tell if the humidifier, active or passive, is working, other than secretion trends?

Joyner: Certainly a start would be to assure the device is turned on and for all

purposes assure it looks and feels (warmth) like it is working correctly with sufficient water feed and temperature probes placed in the correct places. Beyond those setup items, there are few identifiers of proper humidifier function other than examination and mucus status. Evaluating the vapor trail during inspiration can be a useful tool. During inspiration the vapor trail should be visible and represents water vapor being laid down on the artificial airway and presumably hydrating secretions within the patient's airway. A vapor trail present on expiration and disappearing during inspiration would represent reabsorption of water from the artificial airway and secretions. This would result in the desiccation of secretions and possibly cause dried inspissated secretions that are difficult to mobilize.

Lin: Mucociliary transport is the most sensitive to changes in inspired humidity. Optimal mucociliary transport is dependent on the successful relationship between cilia, mucus, and periciliary fluid, which all are optimized under core temperature and 100% relative humidity. Assessing the secretion trends of patients receiving humidification therapy is the key to ensure adequate/optimal therapy benefit.

Wittnebel: While trends in secretion characteristics may reveal inadequate humidification to the RT, it is likely that soon after a negative trend has started, deleterious changes in airway function have already occurred.[6] Trending secretion clearance may in fact represent a later stage in the process of airway injury as it relates to humidification levels. While some would say that the presence of observable condensate in the endotracheal tube is evidence enough for evaluating humidification, current methods limit the RT in determining the actual airway temperature and humidity as most devices simply measure proximal to the patient Y-piece and at the humidification outlet chamber. These temperatures are a reflection of the gas as it is entering the airway. Short of inserting a hygrometer into the actual airway itself, inferences are then made regarding the actual temperature and the humidity of the inhaled gas. It goes without saying that the higher the temperature of the gas, the higher the carrying capacity of the gas as it relates to humidification, but heaters that fail to limit temperature hold the potential to cause inhalation injury.[7] Walking

> Numerous studies have identified a reduction of aerosol delivery efficiency during mechanical ventilation with heated humidification, often with a 40-50% reduction from ambient conditions.
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> - Lin -

the line between too much and too little airway humidification makes it easy to see why so much research and effort has been placed into determining optimal levels.

Where should the RT place aerosol generators to minimize the effects of humidification on aerosol deposition? Should the heater be turned off during the treatment?
Joyner: Positioning of the aerosol generator within the ventilator circuit is still somewhat controversial with some authors advocating placement at least 30 cm away from the airway to allow for the circuit to act as a reservoir,[8] and other authors suggesting aerosol generator position within the ventilation circuit does not matter.[9] The vast majority of clinical sites I am involved with provide some separation between the position of the aerosol generator and artificial airway, but the true effect on outcome is difficult to assess because aerosolized bronchodilators are ordered almost ubiquitously making therapeutic effect difficult to assess.

The status of the heater being on or off is of theoretical importance to the delivery of aerosolized medications. Delivery of aerosolized medications through a ventilator circuit that is being actively humidi-

fied can cause up to a 40% reduction in deposition. This has some practitioners requesting to turn off the humidifier during medication delivery. Under most circumstances this may be acceptable because the treatment will last only 8-10 minutes, but some medications can require 30 minutes or more to deliver. Delivering dry gas to the patient over that period of time could be problematic and is not recommended.[8]

Lin: Numerous studies have identified a reduction of aerosol delivery efficiency during mechanical ventilation with heated humidification, often with a 40-50% reduction from ambient conditions.,[10-12] Lange and colleagues found that the decrease in inhaled drug mass was directly related to the mole fraction of water vapor in the ventilator, rather than to the relative humidity and the temperature. Clinicians try to reduce the influence of humidity on aerosol delivery by turning the heated humidifier (HH) off. Lin investigated pressured metered-dose inhaler delivery after the HH was turned on at 1, 2, 3 hours and immediate after turning the HH off. Aerosol delivered distal to the endotracheal tube remained similar after the HH was fully situated and when the HH was turned off.[13] Generally, the HH requires 20-30 minutes to cool down to room temperature before minimizing the influence of humidity on aerosol delivery. Administered aerosol immediately after the HH was turned off did not improve its efficiency. Ari et al compared aerosol delivery with different devices and locations through mechanical ventilation in an in vitro model.[14] They found that a vibrating-mesh nebulizer, an ultrasonic nebulizer, and a pressurized metered-dose inhaler delivered higher inhaled drug mass at 15 cm from the Y-piece. The jet nebulizer delivered a higher dose at 15 cm from the ventilator. Yet, Moraine et al evaluated the effect of position, either at the end of the inspiratory limb or before the HH, on pulmonary bioavailability of nebulized ipratropium in ventilated patients, and the result showed no statistically significant differences between the 2 groups.[9] The optimal placement of an aerosol generator depends on the devices, and further clinical trials are required to verify the in vitro data.

Wittnebel: The placement of the aerosol generator has been a point of contention amongst researchers, with even the AARC

currently lacking a clinical practice guideline. Despite this, recent research seems to suggest that 15 cm from the Y piece on the inspiratory limb is optimal in regard to particle deposition, with active humidification actually negatively impacting aerosol therapy. The various available modalities including small volume nebulizers (SVNs) metered dose inhalers (MDIs) and vibrating mesh nebulizers have spawned research evaluating particle deposition efficacy under a variety of conditions, both with and without humidification. The use of HMEs which necessitate placement proximal to the patient airway result in the need to (1) remove the HME prior to each aerosol treatment or (2) modify the ventilator circuit-HME-aerosol adaptor set up. Recent improvements in HME design allow for the condensate trapping mechanism to be shifted away from the flow of gas, allowing for the delivery of aerosolized medications without the need to break the circuit as seen in earlier HMEs. Two predominant methods of modification appear to choose to either sacrifice potential circuit contamination in favor of optimal particle deposition or vice versa, as depicted below, while a third option may represent the middle ground:

Set-up 1: *Optimizing Particle Deposition.*
Involves the use of passive (HME) humidification or the placement of a spring-loaded t-piece on the inspiratory portion of the patient Y-Piece, significantly closer than the 15 cm advocated for in previous research.

Set-up 2: *Reducing Potential for Circuit Contamination and VAP.*
Involves the placement of the HME at the patient Y-piece, followed by the spring loaded or MDI adaptor, six inches of large bore tubing, and an inline suction catheter.

Set-up 3: *Avoiding Circuit Contamination and VAP potential while facilitating the delivery of aerosol therapy.*
This requires the use of specialty HMEs which allow for the removal of the condensate trapping mechanism without the need to break the circuit and remove the HME device in its entirety. It is noteworthy that while these devices are more costly than traditional HMEs, they may represent an adequate amalgamation of adequate airway humidification, a reduction in VAP acquisition, and improvements in the ability to administer aerosolized medications without the risks

> ## The practitioner needs to know the temperature at both ends of the ventilator circuit.
>
> - Joyner -

inherent in the other two common device set-ups.

At what location within the ventilator circuit is it most important to monitor temperature: at the water source or at the patient interface?

Joyner: The practitioner needs to know the temperature at both ends of the ventilator circuit. The change in temperature between the source of humidification and the patient's airway is what dictates what will happen to the water contained in the gas being delivered to the patient, and the patient's secretions within the airway. Altering the temperature between the source and the airways even a few degrees can dramatically affect the relative humidity of the gas being delivered to the patient. An excessive drop in temperature within the ventilator circuit can cause large amounts of condensate to develop within the ventilator circuit and place the patient at risk of an unintentional airway lavage and possible increase the risk of VAP. A small increase in temperature as the gas travels through the ventilator circuit toward the patient can result in a significant reduction in relative humidity resulting in the desiccation of secretions in the airway, making them difficult to remove and possibly placing the patient at risk for an obstructed airway.[15]

Lin: Temperature measurement may be a poor indicator of humidity. There is inadequate humidification of mechanical ventilation when minute ventilation greater than 6 L/min.[16] Additionally, a humidification system's performance depends on environmental temperature and ventilatory settings. Schena et al investigated

the performance of a heated humidifier system and confirmed that single-point (at the Y-piece) temperature control was weak.[17] The temperature should be measured both at the water source and at the patient interface, and adjust accordingly to ensure adequate humidity.

Wittnebel: Beyond a shadow of a doubt, it is more important to monitor the temperature at the patient interface, regardless of invasive or noninvasive modality. There are too many potentially confounding variables such as improper set-up, room temperature, and equipment failure, to name a few, to risk patient injury. This coupled with the variability seen between different ventilators makes things all the more unclear while simultaneously all the more important.[18,19]

When observing for beading in the circuit, do the water droplets need to be throughout the entire ventilator circuit or just at the visible part of the ETT and the 6-inch flex tube closest to the patient?

Joyner: Visual inspection of the 6-inch flex tube for water droplets has been shown to be sensitive to the amount of humidification being provided to the patient.[20] Water droplets do not need to be visible throughout the circuit and when they are present they present a risk to the patient as they collect and increase the quantity of condensate within the ventilator tubing. Prevention of aspirating these condensate droplets is important in preventing ventilator-associated pneumonia. [21]

Lin: Condensation can interfere with gas flow through the circuit, and may increase the risk of aspiration and contamination within hours.[2,22] Therefore, the condensation in the circuit should be emptied regularly.

Wittenbel: As previously mentioned, in respiratory care, if condensate was visible in the endotracheal tube then one could assume that adequate humidification was being provided. With the heightened emphasis on ventilator-associated pneumonia and the reluctance to do anything to the circuit that would contribute to its occurrence (including water build-up), it is not unreasonable to speculate that hospitals gladly pay the higher cost of heated wire and other specialty ventilator circuits with the explicit attempt to prevent bead-

ing anywhere along the path between the ventilator and the artificial airway, whether it be in the neonatal intensive care unit via an oscillator or the adult side with conventional ventilation. [23]

Is there any evidence that humidity delivery to the patient in excess of 44 mg/L has a negative effect?

Joyner: First and because this is a discussion on humidity, the only way I can think of that will result in an excess of 44 mg/L is to increase the temperature of the gas in the presence of sufficient water. Also I do not believe there are any current guidelines that define overhumidification. Certainly at some point (likely beyond 41 degrees C) this will become a detriment to airway physiology. Other theoretical issues can arise from a positive water balance for an extended period of time, including excessive pulmonary secretions, pulmonary and generalized edema, weight gain, hyponatremia, decreased pulmonary compliance, reduced vital capacity, and increased A-a gradient.[3]

Lin: Currently, there are no criteria for overhumidification. When the inspired humidity is higher than core temperature and 100% relative humidity, condensation occurs, causing decreased mucus viscosity and possibly increasing periciliary transport rate. Therefore, overhumidification reduces mucus viscosity and dilutes surfactant, resulting in secretion retentionand increased work of breathing.[24]

Wittnebel: Current evidence as advocated by the AARC clinical practice guideline for airway humidification supports the provision of 44 mg/L as the maximum allowable level, which in turn is based on expert panel consensus.[2] As such, further review and stronger multicenter randomized control center trials are needed to determine definitively the upper limits of the safe range.[2]

Is it advantageous to have a humidifier that allows adjustments to absolute and relative humidity?

Joyner: When heated-wire circuits were first introduced in the clinical environment back in the early 1990's there were manageable settings that would allow a practitioner to adjust the proximal and distal temperature within the circuit independently, thereby affecting the absolute and relative humidity being provided

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> overhumidification reduces mucus viscosity and dilutes surfactant, resulting in secretion retentionand increased work of breathing.
>
> *- Lin -*

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to the patient's airway.[25] Today, some of these humidifiers allow the adjustment of the circuit temperature under different ambient conditions to prevent accumulation of condensate and the need to drain the condensate from the ventilator circuit.[26] Under certain circumstances, the temperature of the heated wires within the ventilator circuit can be unintentionally set in a manner that allows inspiratory gas with very low relative humidity to be delivered to the patient's airway. This will result in the desiccation of the respiratory secretions within the artificial airway causing a time-dependent reduction in artificial airway diameter. Dynamic changes in artificial airway diameter can be difficult to differentiate from changes in patient pulmonary mechanics.[27] Therefore, while heated-wire circuits may be extremely useful, a well-informed clinician is required to take full advantage of their adjustability while simultaneously avoiding iatrogenic complications. Sophisticated automated servo-controlled humidifiers emanating data from thermistors and hygrometers within the circuit would be ideal to assure targeted humidity delivery under different ambient conditions. Fortunately, both fixed and adjustable systems currently available meet nationally recommended standards.

Lin: Solomita et al assessed Y-piece temperature and water-vapor delivery with a different heated humidification set up and a wide range of minute volumes.[17] Their results showed that heated wired humidification inadequately humidified the gas when VE>6 L/min. Setting

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a temperature at 35 at the Y-piece does not provide equivalent water-vapor delivery with heated-wire and non-heated-wire humidification, nor does it achieve the recommended physiologic humidification target. Furthermore, Pelosi et al found that, depending on the manufacturer of the heated wire humidification system, the relative humidity depends on the set temperature gradient between the water chamber and the Y-piece.[28] Therefore active measurement and adjustment of a humidification system can ensure adequate humidification to patients undergoing mechanical ventilation.

Wittnebel: Considering the myriad number of variables that impact effective humidification therapy, it is almost unfathomable that such a device would be welcomed across the spectrum of care and incorporated into all devices delivering medical gas therapy. Countless research has been conducted that has demonstrated time and time again that humidification therapy and external variables are not mutually exclusive and thus, not a single device exists. Absolute and relative humidity in the environment play critical roles in what is occurring in the "closed" environment of the patient circuit and as such, a device that could account and control for all situations would optimize the goals and eliminate most of the hazards associated with humidification therapy. While research under a variety of conditions is currently being conducted, such a method of therapy has yet to be discovered.

References

1. Beachey W, Respiratory Care Anatomy and Physiology. 2nd Ed, St Louis: Mosby-Elsevier; 2009:12.

2. American Association for Respiratory Care, Restrepo RD, Walsh BK. Humidification during invasive and noninvasive mechanical ventilation: 2012. Respir Care. 2012;57(5):782-8.

3. Gross JL, Park GR. Humidification of inspired gases during mechanical ventilation. Minerva Anesthesiol. 2012;78:496-502.

4. Wiest GH, Lehnert G, Bruck WM, Meyer M, Hahn EG, Ficker JH. A Heated humidifier reduces upper airway dryness during continuous positive airway pressure therapy. Resp Med. 1999;93(1):21-26.

5. Meduri GU, Turner R, Abou-Shala R, Wunderink R, Tolley E. Noninvasive positive pressure ventilation via face mask: first-line intervention in patients with acute hypercapnic and hypoxemic respiratory failure. Chest. 1996;109(1):179-193.

6. Massie C, Hart R, Peralez K, Richards G. Effects of humidification on nasal symptoms and compliance in sleep apnea patients using continuous positive airway pressure. Chest. 1999;116(2):403-408.

7. Kraincuk P, Kepka A, Ihra G, Schabernig C, Aloy A. A new prototype of an electronic jet-ventilator and its humidification system. Crit Care. 1999;3:101-110.

8. Fink JB, Tobin MJ, Dhand R. Bronchodilator ther-

apy in mechanically ventilated patients. Resp Care. 1999;44(4):53-69.

9. Moraine JJ, Truflandier K, Vandenbergen N, Berré J, Mélot C, Vincent JL. Placement of the nebulizer before the humidifier during mechanical ventilation: Effect on aerosol delivery. Heart Lung. 2009;38(5):435-9.

10. Dhand R, Duarte AG, Jubran A, et al. Dose-response to bronchodilator delivered by metered-dose inhaler in ventilator-supported patients. Am J Respir Crit Care Med. 1996; 154:388-393.

11. Fink JB, Dhand R, Grychowski J, et al. Reconciling in vitro and in vivo measurements of aerosol delivery from a metered-dose inhaler during mechanical ventilation and defining efficiency-enhancing factors. Am J Respir Crit Care Med. 1999;159:63-68.

12. Lange CF, Finlay WH. Overcoming the adverse effect of humidity in aerosol delivery via pressurized metered-dose inhalers during mechanical ventilation. Am J Respir Crit Care Med. 2000;161:1614-1618.

13. Lin HL, Fink JB, Zhou Y, Cheng YS. Influence of moisture accumulation in inline spacer on delivery of aerosol using metered-dose inhaler during mechanical ventilation. Respir Care. 2009;54(10):1336-1341.

14. Ari A, Areabi H, and Fink JB. Evaluation of aerosol generator devices at 3 locations in humidified and non-humidified circuits during adult mechanical ventilation. Respir Care. 2010;55:837-844.

15. Villafane MC, Cinnella G, Lofaso F, et al. Gradual reduction of endotracheal tube diameter during mechanical ventilation via different humidification devices. Anesthesiology. 1996;85(6):1341-1349.

16. Solomita M, Daroowalla F, Leblanc DS, Smaldone GC. Y-piece temperature and humidification during mechanical ventilation. Respir Care. 2009;54(4):480-486.

17. Schena E, Saccomandi P, Cappelli S, Silvestri S. Mechanical ventilation with heated humidifiers: measurements of condensed water mass within the breathing circuit according to ventilatory settings. Physiol Meas. 2013;34(7):813-21.

18. Carter BG, Whittington N, Hochmann M, Osborne A. The effect of inlet gas temperatures on heated humidifier performance. J Aerosol Med. 2002;15(1):7-13.

19. Lellouche L, Taillé S, Maggiore SM, et al. Influence of ambient and ventilator output temperatures on performance of heated-wire humidifiers. Am J Respir Crit Care Med. 2004;170(10):1073-1079.

20. Ricard JD, Markowicz P, Djedaini K, Mier L, Coste F, Dreyfuss D. Bedside evaluation of efficient airway humidification during mechanical ventilation of the critically ill. Chest. 1999;115(6):1646-1652.

21. American Thoracic Society; Infectious Diseases Society of America. Guidelines for the management of adults with hospital-acquired, ventilator-associated, and healthcare-associated pneumonia. Am J Respir Crit Care Med. 2005;171(4):388-416

22. Craven DE, Goularte TA, Make BJ. Contaminated condensate in mechanical ventilator circuits. A risk factor for nosocomial pneumonia? Am Rev Respir Dis.1984;129(4):625-8.

23. Agaya K, Okamato T, Nakamura E, Hayashi T, Fujieda K. Airway humidification with a heated wire humidifier during high-frequency oscillatory ventilation using Babylog 8000 Plus® in neonates. Pediatr Pulmonol. 2009;44(3):260-266.

24. Williams R, Rankin N, Smith T, Galler D, Seakins P. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. Crit Care Med. 1996;24(11):1920-1929.

25. Miyao H, Hirokawa T, Miyasaka K, Kawazoe T. Relative humidity, not absolute humidity, is of great importance when using a humidifier with a heating wire [see comments]. Crit Care Med. 1992;20(5):674-679.

26. Solomita M, Daroowalla F, LeBlanc DS, Smaldone GC. Y-Piece Temperature and Humidification During Mechanical Ventilation. Respir Care. 2009;54(4):480-486.

27. Villafane MC, Cinnella G, Lofaso F, et al. Gradual Reduction of Endotracheal Tube Diameter during Mechanical Ventilation via Different Humidification Devices. Anesthesiol. 1996;85(6):1341-1349.

28. Pelosi P, Chiumello D, Severgnini P, et al. Performance of heated wire humidifiers: An in vitro study. Journal of Critical Care. 2007;22(3):258-264.

Ruben Restrepo, MD, RRT, FAARC is Professor and Director of Bachelor's Degree Completion program in the Department of Respiratory Care at the University of Texas Health Science Center at San Antonio, Texas. Trained in medicine in Medellin, Columbia, Dr. Restrepo went on to academic positions at Georgia State University and then at the University of Texas. He has published widely in the field of respiratory care, including book chapters and articles, and has given many presentations. He is a reviewer for several major journals in respiratory and pulmonary medicine and is the recipient of many honors and awards for his teaching, publications, and volunteer work.

Brian Walsh, RRT-NPS, RPFT, EMT-E, FAARC is Clinical Research Coordinator, Respiratory Care Department and the Department of Critical Care, Children's Hospital, Boston, where he conducts translational and clinical research, develops protocols and budgets, monitors adverse reactions, lectures, and presents research findings to the investigation review boards. He has authored or coauthored 5 textbook chapters and 20 scientific articles on respiratory care topics. He is the 2008 recipient of the Outstanding Alumnus Award from Central Virginia Community College Alumni Association. He is also Vice President for Internal Affairs at the American Association for Respiratory Care.

Hui-Ling Lin, MSc, RRT, RN, FAARC is Assistant Professor, Respiratory Therapy Program, Chang Gung University, Tao-Yuan, Taiwan. She has co-authored over 30 papers, review articles and abstracts related on respiratory care topics. Her professional affilations include membership in the American Association for Respiratory Care, the National Board for the Respiratory Care, the International Society for Aerosol Medicine, the Respiratory Therapists Society of the Republic of China and the Taiwan Society for Respiratory Therapy.

Robert L Joyner Jr, PhD, RRT, FAARC is Associate Dean in the Henson School of Science & Technology. He is also Professor of Health Sciences and Director of the Respiratory Therapy Program at Salisbury University, Salisbury, Maryland. He is an elected member of Lambda Beta (Respiratory Care Honor Society) and in 2007, he was inducted as a Fellow of the American Association for Respiratory Care (FAARC). Dr. Joyner is author or coauthor of more than 3 dozen articles (peer reviewed and non-peer reviewed) and reviews. He sits on 9 professional committees and is a member of the American Physiological Society, the American Thoracic Society, the American Society of Respiratory Care, the National Board for Respiratory Care, and the Society of Critical Care Medicine.

Leo Wittnebel, MSIS, RRT is Assistant Professor in the Department of Respiratory Care at the University of Texas Health Science Center, San Antonio, Texas (UTHSCSA). Leo also works as a respiratory therapist at the Christus Santa Rosa Medical Center, San Antonio. His role there is to provide respiratory care to patients throughout the hospital. Leo has authored or coauthored several publications in the area of respiratory medicine, has given many presentations on the subject, and has an extensive and distinguished teaching record. He is a grant reviewer for the UTHSCSA and participates in the university's Med Ed program. He is also the recipient of several academic and professional honors.

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1. **Under normal conditions, what is the range of absolute humidity delivered by most heated humidifiers available today?**
   A. 26 mg H_2O/L to 36 mg H_2O/L
   B. 26 mg H_2O/L to 44 mg H_2O/L
   C. 33 mg H_2O/L to 44 mg H_2O/L
   D. 40 mg H_2O/L to 44 mg H_2O/L

2. **Most heated humidifiers available today allow the operator to control the humidity level**
   A. True
   B. False

3. **The respiratory therapist is evaluating the humidification system and the ventilator circuit of a patient undergoing invasive mechanical ventilation and notices a small amount of "rainout" in the inspiratory limb of the circuit. What should be the best course of action at this point?**
   A. Replace the heated-wired circuit as it is malfunctioning
   B. Increase the heater temperature
   C. Lower the temperature of the heater
   D. Document that the humidifier function is normal

4. **The presence of abnormally high room ambient temperatures can result in which of the following changes in humidification?**
   A. A reduction in the humidity level as a result of a decrease in the temperature of the heating source
   B. An increase in the humidity level as a result of a higher carrying capacity for water through the ventilator circuit
   C. A reduction in the humidity level as a result of an increase in the temperature of the heating source and higher rate of water consumption
   D. An increase in the humidity level as a result of a decrease in the temperature of the heating source

5. **When using a mechanical ventilator known to have a high outlet gas temperature, what could the respiratory therapist do to offset it to prevent changes in humidity levels?**
   A. Avoid using a heated-wired circuit
   B. Change the ventilator
   C. Lower the temperature of the heater
   D. Extend the length of the tubing prior to the heating chamber

6. **The presence of high relative humidity and temperature within the ventilator circuit is associated with what percent reductions in lung deposition with *in vitro* adult models?**
   A. 10%
   B. 20%
   C. 30-35%
   D. 40-50%

7. **What appears to be the most efficient placement of a jet nebulizer under humidified and nonhumidified condition?**
   A. Before the heater
   B. 6 inches away from the "Y" adapter in the inspiratory limb of the ventilator circuit
   C. 6 inches away from the "Y" adapter in the expiratory limb of the ventilator circuit
   D. Between the "Y" adapter and the endotracheal tube

8. **In order to minimize the reduction of aerosol deposited in the lungs under humidified conditions, the humidifier should be turned off for the duration of the treatment.**
   A. True
   B. False

9. **HMEs are contraindicated when routine aerosol therapy is required during mechanical ventilation.**
   A. True
   B. False

10. **During the administration of NIV, the lack of humidification is frequently associated with which of the following clinical conditions?**
    A. Hypercapnia
    B. Poor compliance
    C. Infection
    D. Skin irritation

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7. Faculty Disclosure. Brian Walsh and Ruben Restrepo disclosed that they are consultants and speakers for Teleflex. No conflicts were disclosed for any other faculty

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1. Discuss the impact of ambient temperatures on heated humidification

   Strongly Agree — Strongly Disagree
   1   2   3   4   5   6

2. List the recommended temperature and humidity levels for intubated patients

   Strongly Agree — Strongly Disagree
   1   2   3   4   5   6

3. Discuss the relationship between aerosol therapy and heated humidification

   Strongly Agree — Strongly Disagree
   1   2   3   4   5   6

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A B C D   A B C D
☐ ☐ ☐ ☐   ☐ ☐ ☐ ☐

A B C D   A B C D
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