Artificial humidification for the mechanically ventilated patient

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Summary

Caring for patients who are mechanically ventilated poses many challenges for critical care nurses. It is important to humidify the patient's airways artificially to prevent complications such as ventilator-associated pneumonia. There is no gold standard to determine which type of humidification is best for patients who are artificially ventilated. This article provides an overview of commonly used artificial humidification for mechanically ventilated patients and discusses nurses' responsibilities in caring for patients receiving artificial humidification.

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MECHANICAL VENTILATION USING artificial airways such as endotracheal and tracheostomy tubes has many complications (Morán *et al* 2006). Appropriate humidification of inspired air is one of the components of the high impact interventions for mechanically ventilated patients (Department of Health (DH) 2007). High impact interventions are part of the care bundle approach that aims to prevent ventilator-associated pneumonia (National Institute for Health and Clinical Excellence (NICE) 2008). Although the provision of heat and humidity for the airways of mechanically ventilated patients is standard practice worldwide, there is considerable confusion among healthcare professionals on what constitutes optimal humidity and how to provide it (Ricard 2007). This article aims to provide readers with an understanding of why artificial humidification is important for mechanically ventilated patients and to help them select the most appropriate method of humidification for patients in their care. It also explores two common methods of artificial humidification: heated humidification and humidification via heat and moisture exchangers.

Heat and moisture exchange

The upper respiratory tract, primarily the nasopharynx, contains a large area of highly vascular, moist, mucous membrane. When air passes through the nasopharynx, it is warmed and humidified on inspiration, and the majority of the heat and moisture on expiration is reclaimed by the nasopharyngeal mucosa; this provides humidification to the rest of the respiratory tract on subsequent inspirations (Lorente *et al* 2006).

The gas that reaches the alveolar level is usually 100% saturated at body temperature, even if inspired air is at extremes of temperature or humidity. The point at which gases reach alveolar conditions is known as the isothermic boundary (Lemin 2009).

Under normal circumstances, the upper airways contribute effectively to heating and humidifying inspired air. However, this process is compromised when the upper airways are bypassed with an artificial airway, such as an endotracheal or tracheostomy tube. In this case the isothermic saturation boundary becomes located further down the respiratory tract with the delivery of cold medical gases during artificial ventilation (Lemin 2009). This results in severe heat and moisture loss from the respiratory mucosa (Ryan *et al* 2002) and impaired mucocilliary clearance – the ability of cilia to clear respiratory secretions – which causes pooling of mucus in the lower airways. Pools of mucus provide an ideal environment for bacterial colonisation, which predisposes the patient to infections such as ventilator-associated pneumonia (Chastre and Fagon 2002). Inadequate heat and humidification may also result in dried secretions and cause atelectasis. Atelectasis can ultimately lead to a decreased functional residual capacity

(the volume of gas in the lungs at the end of normal exhalation) and poor lung compliance, which can severely impair gas exchange (Poolacherla and Nickells 2006). Artificial humidification is therefore an essential aspect of caring for mechanically ventilated patients.

Optimal humidity

Humidity (the level of water vapour in air) can be expressed as absolute humidity or relative humidity (Ryan *et al* 2002). Absolute humidity is the amount of water vapour present in a gas, which is usually expressed as mgH_2O/L. Absolute humidity increases with increasing gas temperature and decreases with decreasing gas temperature (Branson 2007). For example, at a room temperature of 20°C, the absolute humidity of gas is 17mgH_2O/L and by the time gas reaches the lungs it will have been warmed to 37°C and contain 44mgH_2O/L absolute humidity (Lorente *et al* 2006).

Relative humidity is normally expressed as a percentage. The relative humidity of a gas saturated with water vapour at any temperature is 100% and this percentage will fall as the gas temperature rises (Lorente *et al* 2006). Relative humidity measures how much water vapour a gas is holding compared with how much it could hold at that temperature (Branson 2007). An inspired gas that is conditioned to core body temperature (37°C) and has 100% relative humidity is important for an optimal clearance of mucus from the respiratory tract (Ryan *et al* 2002).

After passing through the nasopharynx, the temperature of inspired gas at the carina (the point at which the trachea bifurcates into the right and left bronchi) is 34-37°C, achieving an absolute humidity of 42-44mgH_2O/L and a relative humidity of 100%. This is the optimum humidity for effective mucociliary system function (Lorente *et al* 2006).

Ventilator care bundle

High impact interventions are evidence-based tools. They incorporate care bundles that aim to prevent healthcare-associated infections and reduce the risk of infection to patients by encouraging healthcare staff to comply with evidence-based practice and guidelines every time they undertake a clinical procedure (DH 2007).

A care bundle is a group of evidence-based interventions applied to the management of a particular condition (DH 2007). When these interventions are grouped together in a single protocol this should improve clinical outcomes (Fulbrook and Mooney 2003). The ventilator care bundle comprises a group of interventions that aim to prevent the development of ventilator-associated pneumonia (Box 1) (DH 2007).

No direct relationship has yet been established between inadequate humidification and the occurrence of ventilator-associated pneumonia (Niël-Weise *et al* 2007). The causes of ventilator-associated pneumonia are multifactorial (Kollef 2004). However, it is generally agreed that inadequate humidification of artificial airways leads to mucociliary dysfunction, which results in pooling of secretions that may predispose patients to respiratory infections (Chastre and Fagon 2002, Branson 2007). One theory that seeks to explain the pathogenesis of ventilator-associated pneumonia is the aspiration of contaminated oropharyngeal secretions and fluids such as ventilator tubing condensate (Centers for Disease Control and Prevention (CDC) 2003).

Artificial humidification has a significant role in preventing complications associated with mechanical ventilation (Kollef 2004, Siempos *et al* 2007). Guidelines clearly advocate that artificial humidification is an essential component of caring for mechanically ventilated patients, and it is one of seven identified high impact interventions (DH 2007). There is little consensus in the literature regarding which method of humidification is associated with the lowest occurrence of ventilator-associated pneumonia. Some guidelines on the prevention of ventilator-associated pneumonia do not recommend the use of either heat and moisture exchangers or heated humidification over other methods (CDC 2003, NICE 2008), while others clearly advocate the use of heat and moisture exchangers or heated humidification for the humidification of artificial airways (Lorente *et al* 2006, Branson 2007). Many randomised controlled studies have been conducted to assess which method of humidification is associated with the lowest

BOX 1

Components of the ventilator care bundle

- Elevation of the head end of the bed to 30-45°.
- Sedation holding (regularly stopping sedation).
- Deep vein thrombosis prophylaxis.
- Gastric ulcer prophylaxis.
- Appropriate humidification of inspired gas.
- Tube management.
- Secretion removal by suctioning.
- Routine oral hygiene.

(DH 2007)

occurrence of ventilator-associated pneumonia. Although studies favour the use of heat and moisture exchangers (Memish *et al* 2001, Kola *et al* 2005), their effect on lowering the occurrence of ventilator-associated pneumonia was not consistent nor clinically significant when comparing them with the use of heated humidification (Siempos *et al* 2007).

Methods of artificial humidification

Artificial humidification can be either active or passive (Poolacherla and Nickells 2006). Active humidification is achieved using heated water humidifiers in which gases pass across or over a heated water bath. Passive humidification is achieved with heat and moisture exchange filters attached to the ventilator circuit. Heat and moisture exchange filters mimic the function of the upper airways by trapping, heating and humidifying gas from the patient's exhaled gas within the filter, returning heat and humidity to the inspired gas on a subsequent inhalation (Lacherade *et al* 2005). Heat and moisture exchangers are further classified as hydrophobic heat and moisture exchangers, possessing a bacterial filtration property, or hygroscopic heat and moisture exchangers, which have a humidification property (Niël-Weise *et al* 2007). Many heat and moisture exchangers incorporate paper or polypropylene materials impregnated with a hygroscopic chemical, such as calcium or lithium chloride (Poolacherla and Nickells 2006).

Heated humidification This technique was traditionally used as the primary means of providing artificial humidification (Kollef *et al* 1998). Heated humidification generally consists of a heating source, water chamber or humidification chamber, temperature control unit and a gas/liquid interface (Figure 1) (Poolacherla and Nickells 2006). In this method, the water in a humidification chamber is heated up sufficiently by the heating source to produce water vapour. As the gas is passed through the chamber, it collects the water vapour before reaching the patient's airway. The humidification chamber is usually placed on the top plate of the heating source/humidifier. It has an inlet that receives medical gas and an outlet that delivers the gas to the patient.

The water level in the humidification chamber can be maintained manually or by using an automatic feed system with an integrated float valve inside the water chamber, which regulates and maintains a constant water level. Manual methods are more likely to lead to reservoir contamination and overfilling, while automatic feed systems eliminate these risks and are used more commonly in many intensive care units (ICUs). A control unit regulates the temperature

FIGURE 1
Heated humidifiers

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of the gas that flows through the ventilator circuit, with an inspired gas temperature of 33±2°C being set to provide a minimum of 30mgH_2O/L absolute humidity (Lemin 2009). A heated humidification system can also be used with or without a heated wire breathing circuit (Lemin 2009). It should be noted that, as the humidified gas passes through the breathing circuit, it cools and condenses, causing water to collect within the inlet limb of the circuit. To compensate for this, the gas in the humidifier can be heated to above 37°C; however, in certain circumstances this may increase the risk of thermal injury to the patient, for example when using a breathing circuit without a heated wire. By introducing a heated wire into the breathing circuit the need to overheat the gas in the water chamber is eliminated and there is also a reduction in the formation of condensate in the circuit. The purpose of the heated wire in the circuit is to maintain or raise the gas temperature at or above the dew point (the point at which water condenses), hence eliminating water condensation (Lellouche *et al* 2004). Heated wire breathing circuits may have either a dual limb or single limb circuit. The insulated resistance heating wire runs the full length of the inspiratory and expiratory circuit limbs (Lellouche *et al* 2004).

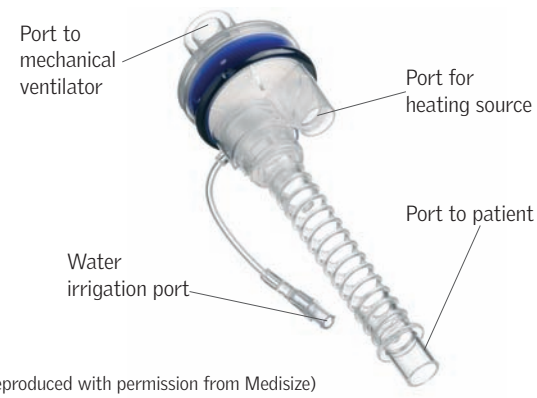
Advantages and disadvantages Heated humidification has demonstrated better gas humidification than heat and moisture exchangers, although there is no evidence to prove a better clinical outcome (Lellouche *et al* 2004). A common disadvantage attributed to heated

humidification is that it increases the risk of condensation and hence condensate in the breathing circuits (Siempos *et al* 2007), thereby increasing the risk of bacterial colonisation within the circuit (Thomachot *et al* 1998). Using a heated wire breathing circuit with heated humidification may reduce the formation of condensate (Niël-Weise *et al* 2007), but there have been no proven advantages compared with the use of non-heated-wire circuits (Branson 2005). Heated humidification does have other disadvantages including high maintenance costs, increased workload for nurses and the risk of endotracheal or tracheostomy tube occlusion caused by incorrect temperature settings (Kollef *et al* 1998). Other disadvantages include risks such as electrical hazards, over or underhydration of gases and injury such as scalds or burns to healthcare personnel (Poolacherla and Nickells 2006).

Heat and moisture exchangers These devices (Figure 2) are used in many intensive care settings (Niël-Weise *et al* 2007). The heat and moisture exchanger is usually attached between the catheter mount secured to the patient's endotracheal tube and the 'Y' connection of the ventilator tubing. Many heat and moisture exchangers provide a moisture output of 22-34mg H_2O/L (Lellouche *et al* 2004). Mechanically ventilated patients with normal secretions may only require an absolute humidity of 26mg H_2O/L to maintain mucocilliary function (Lorente *et al* 2006). However, moisture output changes depending on certain factors such as tidal volume, inspiratory time, respiratory rate and temperature (Inui *et al* 2006). Heat and moisture exchangers are frequently used when a short period (usually less than three days) of mechanical ventilation is anticipated and there is no standard protocol on when to change heat and moisture exchangers.

FIGURE 2

Active heat and moisture exchanger for heated humidification



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Some studies recommend that heat and moisture exchangers can be used safely for three days (Davis *et al* 2000), while others recommend changing them after seven days (Dodek *et al* 2004). However, guidelines on the prevention of hospital-acquired pneumonia suggest that heat and moisture exchangers should not be changed routinely and advise that practitioners should seek guidance from the manufacturers on optimal use and replacement times (Masterton *et al* 2008).

A new version of the heat and moisture exchanger has been developed,which is known as an active heat and moisture exchanger or heat and moisture exchanger booster (Figure 2). This consists of a heat and moisture exchanger, water infusing system and heating element. It functions in a similar way to traditional heated humidification when the heating element and water system are activated. Many ICUs are starting to use these devices, replacing more traditional heated humidification.

Advantages and disadvantages Many authors support the use of heat and moisture exchangers to provide humidification (Kollef *et al* 1998, Kola *et al* 2005). Kollef and colleagues (1998) concluded that heat and moisture exchangers are safe and more cost effective than heated humidification. Heat and moisture exchangers also avoid condensation of liquid in the ventilator circuit and reduce the frequency of ventilator circuit changes (Lorente *et al* 2004). Other advantages associated with heat and moisture exchangers are reduced nursing workload, reduced financial cost and better safety (Memish *et al* 2001). Heat and moisture exchange is also the most commonly preferred method of humidification when transferring critically ill patients between departments and other units. Heat and moisture exchangers are small, easy to set up and carry, and eliminate the need for an electric current, whereas heated humidifiers are heavy and require an electric current to function.

The use of heat and moisture exchangers is contraindicated in certain circumstances, for example in patients with bronchopleural fistula or when the expired tidal volume is less than 70% of the delivered tidal volume, the patient's body temperature is below 32°C and when high minute volumes (the amount of air breathed in and out in one minute) are present (Lemin 2009). Heat and moisture exchangers are associated with an increased risk of airway occlusion (Goldsmith and Shannon 2009) and tube dislodgement (Lawes 2003, Poolacherla and Nickells 2006). Using heat and moisture exchangers can also potentially increase deadspace (the volume of gas that does not participate in gas exchange) and airway resistance thereby increasing the work of breathing for the patient (Goldsmith and Shannon 2009). Finally, these devices are

not recommended for use in patients who produce tenacious and/or copious secretions or who have haemoptysis (Lawes 2003, Lemin 2009).

Nursing implications

Critical care nurses should ensure that patients who are artificially ventilated receive an appropriate method of humidification according to their individual needs. A thorough clinical assessment should be undertaken to identify which method of humidification is most effective for each patient. Issues such as anticipated duration of ventilation, characteristics of any respiratory secretions the patient produces, contraindications and the cost of using one particular method of humidification over another should be considered. A multidisciplinary approach is essential and patient needs and safety are paramount.

Nurses should ensure that they check humidification devices as part of their safety checks during each shift. These checks should be documented in the nursing records. Incompatible humidification devices may pose a danger to patients and staff (Medicines and Healthcare products Regulatory Agency (MHRA) 2007) and it is recommended that personnel should avoid using a breathing circuit that is not designed for heated humidification. Such use might result in over or underheating or possible thermal injury to the patient's airway. Under no circumstances should a heated wire breathing circuit be covered with bed linen, towels or surgical drapes since this may result in melting of the breathing circuit (MHRA 2007) and is a fire hazard.

Damaged humidifiers and wires should be sent for immediate repair according to the manufacturer's instructions and local policy. Care should be taken to avoid accidental drainage of condensate into the patient's airway when repositioning the patient. Particular attention should be given to heat and moisture exchangers to ensure that they do not become blocked with secretions or blood since this may increase resistance, impede gas flow and affect efficacy in proving adequate humidity (Jaber *et al* 2004). If there are any signs of contamination, such as visible secretions (sputum or blood) and water condensate, the practitioner should replace the filter immediately. Although routine changing of heat and moisture exchangers is not recommended, they should be changed according to the manufacturer's recommendations or when clinically warranted (Masterton *et al* 2008) and in line with local infection control policy.

In clinical practice, the ventilator circuit is frequently disconnected for the delivery of nebulised solutions such as 0.9% sodium chloride or bronchodilator medication, and this may increase circuit contamination. In such circumstances, a metered dose inhaler adaptor can be placed between the heat and moisture exchanger and the catheter mount to enable the administration of metered dose inhalers without disconnecting the circuit. The patient's sputum characteristics should be assessed at each suction procedure. If the secretions become thick and copious then heated humidification should be considered (The Intensive Care Society 2008), since it improves secretion management (Lawes 2003, Lemin 2009) and eliminates the need to break the circuit for frequent administration of nebulisers to maintain tube patency. Many clinical areas now use heated wire breathing circuits with metered dose inhaler adapters. There are also new versions of closed suction systems available that have an additional metered dose inhaler port. This enables metered dose inhalers to be administered without having to break the ventilator circuit.

Disposal of heat and moisture exchangers and heated wire breathing circuits should be carried out according to local infection control policy and the manufacturer's recommendations. Humidification chambers usually become hot soon after use and so careful attention is needed when disposing of them to avoid the risk of fire and/or scalding the practitioner. Heater wires and temperature probes are not disposable and should be cleaned and retained for future use as per local policy. Multidisciplinary team members should be made aware of the non-disposable nature of this equipment since replacement necessitated by inadvertent disposal increases the cost of using such systems. Team members should be aware of the range of humidification devices available in their clinical area and have a clear understanding of how to use them. Staff training should be provided as soon as possible, especially when using new products, to prevent any untoward events . Clear and accurate documentation is vital and should include any issues that may arise in the use of a particular method of humidification. It is also important to seek advice from experts when required.

Conclusion

Artificial humidification of inspired respiratory gases is important and can prevent a number of complications associated with mechanical ventilation. Several authors believe that higher levels of airway humidity (44mg H_2O/L) can enable maximal mucocilliary clearance which can only be given with heated humidification (Williams *et al* 1996, Lorente *et al* 2006). In contrast, others believe that gas containing around 26mg H_2O/L is appropriate in most cases, and heat and moisture exchangers can provide this level of humidification

(Lellouche *et al* 2004, Lorente *et al* 2006). However, a multidisciplinary approach should be adopted when selecting humidification devices and decisions should be based on factors such as the patient's clinical needs, safety, cost effectiveness, impact on workload and reduction of risks associated with condensate formation **NS**

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