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*Review articles*

# A review of the mechanisms and methods of humidification of inspired gases

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A bewildering variety of humidifiers is currently available to artificially heat and humidify a patients inspired gases. This review aims to discuss the reasons for their use by examining the normal mechanism of heat and moisture exchange and the consequences of altering the amount of heat and moisture supplied to the respiratory tract. The different types of humidifier are described and their indications, limitations and hazards discussed.

## Normal mechanism of humidification

Under normal circumstances, the nose and upper respiratory tract heat and humidify inspired air so that within the lung, conditions remain constant. Heat and moisture are conserved during expiration but under normal conditions, approximately 250 ml of water and 350 kcal of heat are lost from the lungs each day [1]. Water is lost as saturated vapour in the expired gases and heat is lost since the latent heat of vapourisation of that water was taken from the body. As the specific heat of air is low, little heat is lost as a direct result of heating the inspired air.

Inspired air can be at a wide range of temperatures and humidities [1] but alveolar gas is fully saturated with water vapour at body temperature [2]. A gradient therefore exists between the nose and the point where gas reaches 37 °C and 100% relative humidity (44 mg/l), the isothermic saturation boundary (ISB) [3]. This is normally just below the carina in adults and varies its position with alterations in the heat and moisture content and in tidal volume of inspired gas [4]. Above the ISB, the airway acts as a counter current heat and moisture exchanging system facilited by a turbulent gas flow; below this point the levels of heat and humidity remain constant and gas flow becomes laminar. Conditioning of the inspired gas, therefore, depends on its volume and composition and occurs within the airway itself.

Endotracheal intubation bypasses most of the normal heat and moisture exchanging areas reducing their ability to condition inspired gases so that more heat and moisture is lost during ventilation. In addition, since the ISB is shifted further down the respiratory tree [4], the levels of heat and humidity found in the respiratory tract are altered and pulmonary mechanics are changed [5]. Under these circumstances, ventilation with medical compressed gas (MCG), which is delivered to the patient at room temperature but has a negligible water content, aggravates the situation by shifting the ISB further down the respiratory tract [4]. Conversely, ventilation with gases artificially heated and saturated with water vapour may move the ISB cephalad adding heat and water to the system and again altering pulmonary function.

## Consequences of under humidification

Ventilation with dry gas causes physiological changes. The extent of these changes is related to the degree of humidification of inspired gas [6, 7] and they can be classified as resulting from heat loss, moisture loss or altered pulmonary mechanics.

### *Heat loss*

Since up to 33% of basal heat production in infants may be required to heat and humidify dry inspired gases [8, 9] loss of this heat may result in a considerable drop in core body temperature and is associated with a large respiratory water loss. The mean rectal temperature of neonates fell by 1.4 °C during the first hour of ventilation with dry gas [10], while in

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adults, a 3.3 °C drop in nasopharyngeal temperature has been observed over 3.7 h of surgery [11]. This drop in body temperature appears to correlate with the extent of postoperative shivering [11].

*Moisture loss*

There is a considerable loss of moisture from the respiratory tract during ventilation with dry gases resulting, not only in heat loss but also in a substantial drop in body weight due to dehydration. A weight loss equivalent to 2% body weight has been reported in rabbits following 6 h of dry gas ventilation [8]. Dehydration of the respiratory tract causes epithelial damage, particularly in the trachea and upper bronchi [12]. The degree of histological damage appears to be directly proportional to the duration of ventilation with dry gases [8] and functional impairment may be evident within 10 min [13]. Several histological lesions have been reported [6, 8]:

a. Destruction of cilia and damage to mucous glands,
b. Disorganisation and flattening of pseudostratified columnar epithelium and cuboidal epithelium,
c. Disorganisation of basement membrane,
d. Cytoplasmic and nuclear degeneration,
e. Desquamation of cells,
f. Mucosal ulceration,
g. Reactive hyperaemia following damage.

The most important result of these changes is impaired function of the mucociliary elevator [8, 12, 14–17]. This leads to sputum retention and atelectasis. Damage to the basement membrane together with cellular loss leads to reduced tissue elasticity with ultimate collapse of bronchioles, mucosal swelling and atelectasis. Recovery of both structure and function is inversely proportional to the duration of dry gas ventilation [8]; repair of ciliary damage takes 2–3 days, while repair of full thickness epithelial lesions takes 2–3 weeks [6].

*Altered pulmonary function*

The downward shift of the ISB during ventilation with dry gases alters pulmonary mechanics causing hypoxaemia. There is a fall in functional residual capacity and static compliance and a rise in alveolar arterial oxygen tension difference; these changes are thought to reflect areas of atelectasis with intrapulmonary shunting [5, 17, 18]. Surfactant activity is impaired during dry gas ventilation leading to an increase in surface tension [12, 17].

In sensitive individuals, dry gases act as a potent bronchoconstrictor further compromising respiratory function [8, 12].

Humidification of inspired gases has been shown to decrease the incidence of postoperative pulmonary complications and increase postoperative arterial oxygen tensions [11, 19]. These studies used clinical as well as radiographic signs as an index of postoperative morbidity. Another study [20] failed to show a difference in the incidence of postoperative pulmonary complications between humidified and non-humidified groups but used only radiographic signs which provide a less sensitive index [19, 21, 22].

## Consequences of over humidification

The excessive artificial humidification of inspired gases may produce a situation as unphysiological as ventilation with dry gases. The dynamic equilibrium of heat and moisture exchange in the upper airway is replaced by a more static environment [3] and heat and moisture may be added to the body.

*Heat gain*

Heat may be supplied to the respiratory tract if inspired gases are heated to above body temperature and saturated with water vapour. Mucosal heating [1] or burning may occur [9] causing pulmonary oedema and stricture formation [23]. In addition, because heat cannot be lost via the lungs, hyperthermia may ensue [1].

*Moisture gain*

Maintenance of an accurate fluid balance is made more difficult if inspired gases are overhumidified. Not only is the insensible water loss considerably reduced but water may be added to the body leading to water intoxication [24]. Reports of the physiological changes occurring from overhumidification of inspired gases are sparse but the following have been described:

a. degeneration and adhesion of cilia in the secondary and peripheral bronchi [12],
b. irregularities of the surface of mucus droplets [12],
c. an increased volume of secretions due to decreased evaporation [20],
d. the increased volume of secretions may exceed the capacity of the mucociliary elevator [20],
e. condensation of water droplets within the airways may block them resulting in atelectasis [12],
f. cool water droplets may cause mucosal cooling [9].

*Altered pulmonary function*

Movement of the ISB cephalad results in altered pulmonary mechanics. Overhumidification of inspired gases leads to a fall in functional residual capacity and static compliance together with arterial hypoxaemia [5]. These changes are again thought to reflect atelec-

Table 1. Recommendations by various authors for absolute humidity provided to inspired gases at the mouth in animals, non-anaesthetised and anaesthetised man

| Author | Experimental conditions | Temperature (°C) | Relative humidity (%) | Absolute humidity ($mg H_2O/l$) |
|---|---|---|---|---|
| Animal Studies | | | | |
| Noguchi 1973 [5] | Pulmonary function in dogs | 20.0 – 30.0 | 100 | 17.4 – 30.5 |
| Forbes 1973 [15] | Mucus flow in dogs | 37.0 | 75 | 33.5 |
| Forbes 1974 [16] | Mucus flow in dogs | 32.0 – 37.0 | | 33.0 |
| Mercke 1975 [25] | Ciliary function in rabbits | 35.0 – 37.0 | 60 – 65 | 23.9 – 29.0 |
| Tsuda 1977 [12] | Surfacant analysis and histology in dogs | 25.0 – 30.0 | 100 | 23.2 – 30.5 |
| Non-anaesthetised man | | | | |
| Ingelstedt 1956 [26] | Cricothyroid puncture, room air, nose breathing | 32.0 | 98 | 33.7 |
| | Mouth breathing | 30.5 | 90 | 28.4 |
| Dery 1973 [4] | Nose breathing, subjects, room air, larynx | 33.2 | 69.5 | 25.0 |
| | 9 cm below cords | 35.0 | 88 | 35.0 |
| Anaesthetised man | | | | |
| Chalon 1979 [11] | Mucosal damage and postoperative complications | 32.0 | 100 | 34.4 |
| Chalon 1981 [28] | Review of previous studies | | | 28.0 – 32.0 |
| Weeks 1981 [29] | Ciliary function | | | 14.0 – 22.0 |
| | Pulmonary mechanics | | | 17.0 – 30.0 |

tasis and intrapulmonary shunting. Surfactant activity decreases rapidly with overhumidification of inspired gases, the changes being more marked than with underhumidification. This may be the result of atelectasis inhibiting surfactant production or release; surfactant inactivation or displacement by intra-alveolar fluid; or possibly dilution of surfactant by condensed water [12].

## Optimal humidification levels

Humidification of inspired gases is optimal when the ISB is returned to its original position so that the conditions which normally prevail in the respiratory tract are simulated. Table 1 summarises the humidification levels measured in animals, non-anaesthetised and anaesthetised man by different authors. The heat and moisture exchanging mechanisms in animals appear to be similar to those of man. In man, the temperature at the mouth is approximately 32 °C and the mean absolute humidity at the mouth considered optimal is 27.3 mg $H_2O$/l. Humidification of inspired gases to this level should preserve mucociliary function and pulmonary function in most cases.

## Methods of humidification

Many different humidifiers are available to artificially humidify inspired gases. The properties desirable in these devices are detailed in Table 2.

As well as the ability to deliver adequate levels of heat and moisture to the patient, a humidifier should have other properties. It should be safe with no risk of malfunction [29], electrical hazard, misconnection, disintegration, inhalation debris [30], leakage or drug interaction [31] and should have appropriate physical properties. These will depend on the type of humidifier and its position within the breathing circuit, however, size, resistance, functional dead space and internal compliance are important considerations. The device should be convenient to use, clean and store, and both capital and running costs should be acceptable.

Microbiological safety is important when the protective functions of the upper airway are bypassed and organisms are able to enter or leave the bronchial tree directly. Immunocompromised and heavily infected patients are particularly at risk but the humidifier should not provide a microbiological hazard to any patient. Organisms should be unable to survive or multiply within the equipment itself nor should it increase the incidence of colonisation of the breathing system.

Several different types of humidifier are currently available. The level of humidification delivered by each type is shown in Table 3 and their other properties are summarised in Table 4.

Table 2. The properties desirable in an ideal humidifier

1. Provision of adequate levels of humidification
2. Maintenance of body temperature
3. Safety
4. Lack of microbiological risk to the patient
5. Suitable physical properties
6. Convenience
7. Economy

**Table 3.** Absolute humidity of inspired gases delivered to the patient's mouth having passed through different humidifiers [32, 33]

| | Cold water | Hot water | Nebuliser | HME |
|---|---|---|---|---|
| Temperature °C | 18–23 | 36–38 | 23–36 | |
| Relative humidity % | < ~100 | 100 | >100 | |
| Absolute humidity mg/l | 15–20[a] | 42–47 | 177–1536 | 27–36[b] |

HME = Heat and moisture exchanger; [a] = value of absolute humidity if entrained air also humidified; [b] = value of absolute humidity delivered to patient includes 3 mg/l for heat and moisture exchanging ability of catheter mount

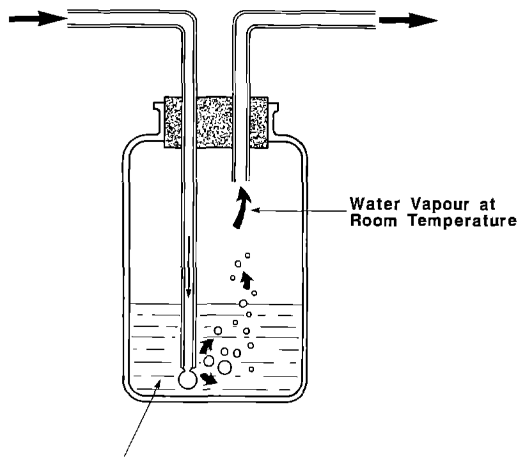


**Fig. 1.** A bubble through cold water humidifier. The gas bubbles through water in the reservoir which is at room temperature; the resulting vapour is also at room temperature

### *Cold water humidifiers*

There are two types of cold water humidifier: the drawover type, where gas is directed over the surface of the water and the bubble variety, Figure 1, where gas bubbles through the water before delivery to the patient. A wick may be included in the humidifier to increase the surface area of the water exposed to dry gas. The level of humidification achieved by these humidifiers is limited by the surface area of the gas/water interface and the temperature of the water. Newer varieties include an air entrainment facility so that all the gas delivered to the patient is saturated at room temperature.

The cold water humidifier is simple to use and inexpensive. However, microbiological colonisation of the reservoir water may occur [34] as well as gas leakage at its connections.

### *Hot water humidifiers*

The way in which a hot water humidifier generates a saturated vapour varies according to its heat source. Many have reservoirs with submerged heat sources, Figure 2, but some employ adjacent heat sources or heating chambers or plates to vapourise part of the reservoir at a time. In theory they are the most versatile of humidifiers, since the absolute humidity of the inspired gases can be altered by changing the temperature of the water bath. In practice, this facility is not available on all models and several generate saturated vapour at a preset temperature only. Since hot water humidifiers are capable of delivering a saturated vapour at a high temperature, over-humidification may occur. In order to minimise the risks to the patient, hot water humidifiers are becoming increasingly complex in design with integral temperature monitors and servo-controlled thermostats.

Bacterial colonisation of the water in the humidifier reservoir [35] and of condensed water in the breathing circuit may occur with the use of hot water

**Table 4.** Comparison of the properties of the different types of humidifier

| | Cold water | Hot water | Nebuliser | HME/HMEF |
|---|---|---|---|---|
| Maintenance body temperature | No data | Good | May cause topical cooling | Good |
| General safety | Gas leakage | Electrical, equipment damage | Electrical | Inhalation debris (HME[a]), blockage possible |
| Microbiological safety | Reservoir contamination | Reservoir contamination, circuit contamination | Reservoir contamination, circuit contamination, aerosol contamination | Reduces circuit contamination, HMEF provides microbiological filtration |
| Physical properties | Low internal compliance | Moderate to high internal compliance | Low internal compliance | Low internal volume, low resistance |
| Convenience | Easy to use, disposable | Bulky, require filling | Bulky, require filling | Easy to use, disposable |
| Cost | Moderate | High | High | Low |

HME = Heat and moisture exchanger; HMEF = Heat and moisture exchanging filter; [a] = see text

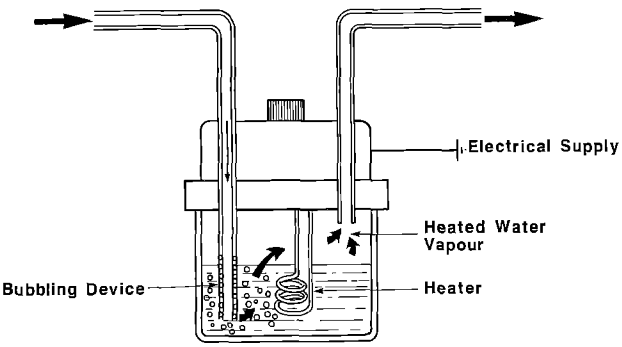


**Fig. 2.** A hot water humidifier. The gas bubbles through the water which is heated by an immersed heating element; gas leaving the device is saturated with water vapour and is heated to a preset temperature

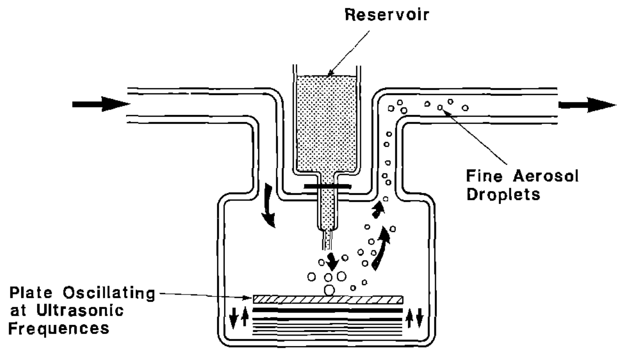


**Fig. 3.** An ultrasonic nebuliser. An aerosol of water droplets is generated by a plate oscillating at ultrasonic frequencies. This is delivered to the gas flow producing a supersaturated mist at or just above room temperature

humidifiers [36, 37], and this may be a source of nosocomial infection [38–40]. The risk may be reduced by adding chlorhexidine to the reservoir water [41], by maintaining the reservoir water at a temperature above 60 °C so that pasteurisation occurs or by use of a sterile closed delivery system. Because of the risk of inhalation of hot water or dilute chlorhexidine and of over-humidification, the latter solution would appear safest.

Condensation of water in the breathing circuit may also damage ventilator valves and other equipment leading to malfunction and risk to the patient [29]. The problem may not be controlled by water traps which also add to the complexity of the breathing circuit. Heating or lagging the circuit will reduce the amount of condensation but expose the patient to a high inspired gas temperature.

Further problems of hot water humidifiers include the possibility of inaccurate thermostats, electrical malfunction and a high internal compliance; their size may cause difficulties in storage and positioning during use; they require sterilisation between use and are expensive. Hot water humidifiers have been shown to degrade halothane to products of undetermined nature and toxicity [31].

### *Nebulisers*

Nebulisers produce water droplets in one of three ways. The Bernoulli effect is used by the gas driven device, the centrifugal generator employs a spinning disc and the ultrasonic nebuliser, a transducer oscillating at ultrasonic frequencies, Fig. 3. Nebulisers do not produce water vapour but a super-saturated mist of water droplets, at or just above room temperature.

Administration of water droplets directly into the respiratory tract may result in large quantities of water being delivered to the patient with subsequent increased airway resistance [42], atelectasis [43] or water overload [24]. The fate of water droplets within the respiratory tract is unclear but it is possible that contaminated droplets may reach bronchiolar or alveolar level presenting a considerable microbiological hazard to the patient [44]. Because the droplets are not warmed, a patient nursed in an environment humidified by a nebuliser, such as an oxygen tent, may be at risk of hypothermia. In addition, nebulisers may present an electrical hazard and are expensive.

### *Heat and moisture exchangers*

All heat and moisture exchangers (HMEs) conserve heat and moisture during expiration and return these to the inspired gas but their mechanisms of action differ [45]. The condenser humidifier operates by condensation of water vapour in the expired gas and its evaporation on inspiration [46]. The hygroscopic HME, Fig. 4, chemically adsorbs a proportion of the expired water vapour onto the humidifier element; this is collected by dry inspired gases [47]. The hydrophobic HME relies on the low thermal conductivity of its element to allow a temperature gradient to

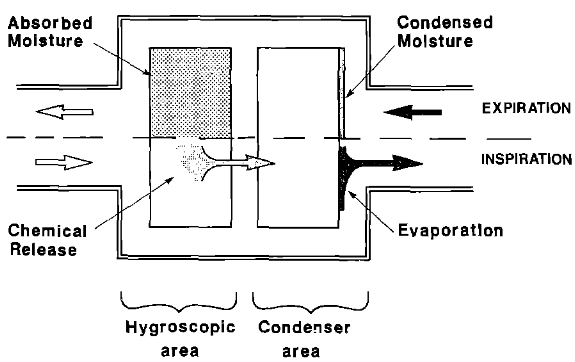


**Fig. 4.** A hygroscopic heat and moisture exchanger. Water vapour in the expired gas condenses onto the humidifier element and some is absorbed by chemicals coating the element; on inspiration this water is taken up by the dry inspired gases and delivered to the patient

develop within the humidifier as the latent heat of vaporisation is taken from the fresh gas [48, 49]. The amount of water lost through the HME is therefore less than a conventional condenser humidifier but will depend upon the magnitude of the temperature gradient produced. Many comparative investigations of individual HMEs have been performed [45, 50–53] and some provide optimal humidification to inspired gases.

HMEs may present a barrier to the passage of bacteria [54] but the antibacterial properties claimed for some have not been substantiated [55–57] and only one HME also acts as a microbiological filter [45, 58]. Contamination of the breathing circuit with condensed water is minimised with a HME thus reducing the microbiological risks to the patient and equipment damage [59]. In addition, they are convenient to use and inexpensive. Use of a HME poses no electrical hazard but does slightly increase the resistance and internal volume of the breathing circuit. Blockage of the HME with secretions will lead to an increased airway resistance and disintegration of some humidifier elements has occurred [30]. HMEs should not be used in conjunction with a hot water humidifier as the combination may be potentially hazardous.

### *Other methods of humidification*

A number of other methods have been used to increase the humidity of inspired gases. During anaesthesia, the use of a breathing system with a low fresh gas flow provides some humidification of inspired gases due to rebreathing. Cooling of the gases before inspiration, however, reduces the level of humidification achieved [60]. Modifications of a standard circle circuit have been suggested [28, 60] and these, or the use of a HME provide more efficient humidification of the inspired gases.

The addition of water to the reservoir bag or tubing of the breathing system increases the level of humidification in the circuit only slightly and may lead to microbiological colonisation.

Intermittent instillation of saline into the trachea is used to loosen mucus plugs prior to physiotherapy [22, 44]. This technique does not humidify inspired gases and its value in the thinning, mobilising and removing of dried secretions has been challenged [61].

## Indications for humidification

Artificial humidification of inspired gases is necessary if the ISB is likely to be moved downwards from its original position. This occurs if the normal mechanisms for humidification of inspired gases are bypassed but the extent of the change may be greater if pulmonary pathology is present. Although many types of humidifier are available, none is ideal for all indications; however, suggested indications for each type of humidifier are summarised in Table 5. The type used will depend on; the airway and mode of ventilation; whether the patient is anaesthetised or receiving intensive care; the patients age and the presence of pulmonary pathology.

**Table 5.** Suggested indications for different types of humidifier

| Humidifier | Indications |
|---|---|
| None | Oxygen therapy using a Venturi entrainer, anaesthesia without intubation, permanent tracheostomy |
| Cold water humidifier | Prolonged use of high flow medical compressed gas |
| Hot water humidifier | Temporary tracheostomy, anaesthesia, intensive care, paediatric patients, oxygen tents and head boxes |
| Nebuliser | Oxygen tents and head boxes, high frequency jet ventilation |
| Heat and moisture exchanger | Temporary tracheostomy, anaesthesia, intensive care, transport ventilation |

### *Airway and mode of ventilation*

A patient breathing spontaneously through his normal airway should humidify his inspired gases adequately [8] and maintain the position of his ISB. Additional humidification is, therefore, unnecessary in a patient receiving controlled oxygen therapy. If the flow of MCG is high and the treatment prolonged the uncomfortable drying of the nose, mouth and pharynx that occurs may be reduced by passing MCG through a cold water humidifier.

Endotracheal intubation bypasses the normal mechanisms of humidification and additional humidification is required. The humidification requirements of a patient with a tracheostomy will depend upon its type. Although the airway is bypassed, a patient with a permanent tracheostomy rarely requires humidification of his inspired gases. New equilibria are presumed to be established and compensations made for the new ISB position. Additional humidification of the inspired gases can be provided, usually with a HME, if dryness or casts around the stoma site are a problem.

A patient with a temporary tracheostomy has different requirements for humidification; these reflect both the pathology necessitating tracheostomy and the need to preserve the respiratory mucosa so that function is restored when the tracheostomy is closed. Both hot water humidifiers and HMEs are used to humidify the inspired gases of a patient with a tracheostomy. A hot water humidifier provides humidified gases with known fractional inspired oxygen concentration ($F_iO_2$) to both the ventilated and spontaneously breathing patient. HMEs provide adequate humidification and a known $F_iO_2$ to ventilated patients but those designed for use in spontaneously breathing patients with a tracheostomy, provide additional but unquantified inspired oxygen.

A spontaneously breathing patient may be sensitive to the small additional resistance or dead space of a HME but this is not usually clinically significant. When ventilation is controlled, these factors can be overcome but in some modes of assisted ventilation, they may become important when added to the work required to trigger the ventilator. The internal compliance of hot water humidifiers may also become significant during assisted ventilation.

Humidification of inspired gases during high frequency jet ventilation is difficult to achieve and the methods currently available are not satisfactory. Lack of humidification results in histological damage [62–64]. Humidification of the driving gas is probably the most reliable method [65] but humidification of the entrained gas or instillation of water into the airway are also used [64, 66, 67].

### *Anaesthesia and intensive care*

There is no clinical evidence that additional humidification of inspired gases is necessary during anaesthesia unless the patients' normal airway is bypassed. When it is, a HME is frequently employed because they are effective, convenient to use and inexpensive [45, 58, 68]. Most HMEs require approximately 15 min to reach equilibrium and will not be functioning optimally during this period [27], however, the heat and moisture exchanging filter (HMEF) reaches equilibrium almost instantaneously [58]. Benefit from HMEs slow to reach equilibrium will, therefore, be slight if the intubation time is less than 30 min unless the patient has pre-existing pulmonary pathology or is hypothermic when further physiological impairment may be detrimental.

Hot water humidifiers are occasionally used during anaesthesia, particularly for paediatric patients and for prolonged procedures. However, in spite of the infection risk, their main use is in the intensive care unit, where their potential versatility makes them particularly useful for the patient with pulmonary pathology or with viscid and tenacious sputum.

HMEs are increasingly used for patients receiving intensive care and their advantages and disadvantages compared with a hot water humidifier are summarised in Table 6. They provide adequate humidification [69–71] and are especially valuable for the patient requiring short term ventilation and those without significant lung pathology. The combined HME and microbiological filter (HMEF) may be particularly valuable in the intensive care unit since it reduces the incidence of nosocomial infection and the necessity for frequent changes of breathing circuit [72].

**Table 6.** Suggested advantages and disadvantages of using a hot water humidifier and a heat and moisture exchanger (HME)

| | Hot water humidifier | HME/HMEF |
|---|---|---|
| Advantages | Adequate humidification, good temperature control, versatile | Adequate humidification, good temperature control, reduces infection risk, cheap, convenient, no power source |
| Disadvantages | Infection risk, overhumidification risk, electrical hazard, internal compliance, expensive, large and awkward, may degrade halothane | Added resistance, internal volume, 2 way gas flow required |

During transport of critically ill patients around or between hospitals, transport ventilators are frequently used without provision for the humidification of inspired gases. Furthermore, the transport ventilator may be colonised with bacteria, with the consequent risk of infection to the patient. Both these problems may be overcome by the use of a combined HME and microbiological filter [73].

### *Age*

The problems seen in adult patients with over- and under-humidification of inspired gases also occur in paediatric patients [23, 24, 74]. Not only are children particularly sensitive to heat loss or gain, they are at risk of blockage of the endotracheal tube by viscid secretions or condensed water droplets. In addition, the dead space, resistance and internal compliance of the humidifier may be important unless compensated for by controlled mandatory ventilation.

HMEs are convenient for use in paediatric patients and provide some humidification [75]. However, since a HME requires a two way gas flow to function optimally, the use of an uncuffed endotracheal tube reduces their efficiency. A hot water humidifier provides effective humidification of inspired gases but its use is more complex and a modified breathing system may be necessary [76]. Adequate humidification of inspired gases is even more important in neonates when further problems may be encountered [77, 78].

### *Pulmonary pathology*

The heat and moisture requirements of patients with normal lungs are relatively predictable but patients with impaired pulmonary function require special consideration [8]. Their mechanisms for heat and moisture homeostatis may be altered by disease [1] and the position of their ISB changed. However, the aim of humidification is still to return the ISB to its physiological position.

Smoking tobacco damages pulmonary ciliated epithelium and impaires ciliary function. Damage to the airways of smokers will, therefore, be increased by inadequate humidification of inspired gases and smokers have been shown to have an increased incidence of postoperative respiratory complications [28].

The quality and quantity of secretions aspirated from the respiratory tract, may be influenced by the humidifier. Small quantities of sputum are rarely a problem unless tenacious and viscid. Systemic rehydration may facilitate the removal of such secretions and a hot water humidifier may reduce their viscosity. Pulmonary oedema fluid, if excessive, may cause blockage of a HME.

A high inspired humidity has been used in the management of croup and asthma but evidence supporting its benefit is anecdotal. While adequate humidification is important, high levels of humidification may increase anxiety and precipitate bronchospasm [79, 80].

## Conclusion

Adequate humidification of inspired gases is important to avoid the hazards of under- and over-humidification. However, each patient will have an optimal level of humidification and as the condition of the patient changes so may his humidification requirements. At present, equipment to monitor humidity is not sufficiently sophisticated to allow accurate breath by breath measurements of humidity within the airway. The estimation of humidification requirements must, therefore, be based on existing scientific evidence and clinical impressions. Humidification of inspired gases should not be considered in isolation but as part of total airway management. It should be associated with careful fluid balance, physiotherapy, bronchial aspiration and appropriate drug therapy.

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