

# Cold Bubble Humidification of Oxygen

## Old habits die hard

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**O**XYGEN THERAPY IS A WIDELY USED TREATMENT modality which, when administered correctly, can be life-saving. Published data have demonstrated that a large proportion of doctors and nurses have been unable to accurately follow the proper methods for administration of oxygen.<sup>1,2</sup> Administration of oxygen through cold bubble humidifiers is part of the generic approach to acute respiratory failure due to a whole host of causes, especially in poorly resourced health systems.<sup>3,4</sup> This article attempts to systematically challenge the age-old practice of cold bubble humidification by questioning the norm of prescribing 'moist oxygen' to all patients irrespective of oxygen flow rate. To establish our views, we have elucidated the concepts of low-flow and high-flow oxygen therapy, the physiology and physics of humidification and the risks of infections associated with cold bubble humidifiers. Finally, we have concluded that cold bubble humidifiers are unable to meet the physiological needs of the upper airway, thereby rendering them far less effective when compared to heated humidifiers.

### Low Flow and High Flow Oxygen

Oxygen delivery systems have always remained a critical component of patient care both in hospitals or otherwise.<sup>3</sup> Devices for the delivery of medical oxygen can be broadly categorised on the basis of oxygen flow rates into high-flow and low-flow devices. The required flow rate is determined for individual patients on the basis of their peak inspiratory flow rate, which in turn is dependent on each patient's pre-existing respiratory ailment.<sup>3</sup>

Low-flow oxygen therapy devices are also known as variable performance devices.<sup>4</sup> These devices deliver a variable fractional inspired concentration of oxygen ( $\text{FiO}_2$ ) according to the variations in minute ventilation (variations in tidal volume, respiratory rate and inspiratory flow) of a patient. Although the device delivers 100% oxygen to the upper airway, the final

$\text{FiO}_2$  delivered is the result of mixing variable amounts of inhaled room air.<sup>5</sup> Severely breathless adult patients often generate inspiratory flows of greater than 40–60 L/min. As the low flow devices usually supply oxygen at flow rates (maximum 15 L/min in India) lower than the dyspnoeic patient's inspiratory demand, a variable amount of room air is required to achieve the required flow.<sup>3,4</sup> Therefore,  $\text{FiO}_2$  in inspired air varies substantially. Examples of commonly used low-flow or variable performance oxygen therapy devices are nasal cannulae, simple face masks and partial rebreathing and non-rebreathing reservoir masks.<sup>5</sup>

High-flow or fixed performance devices such as air entrainment masks, large volume nebulisers and high-flow nasal cannulae (HFNC), provide oxygen at flow rates adequate enough to meet the inspiratory demands of the patient.<sup>5,6</sup> These devices blend 100% oxygen with room air to produce a final inspired gas with the desired  $\text{FiO}_2$ . They also provide an inspiratory flow high enough to exceed any tidal volume, respiratory rate and inspiratory flow a breathless patient might usually generate, thereby preventing dilution of  $\text{FiO}_2$  by entrained room air. Therefore, high-flow, fixed-performance devices deliver a predictable  $\text{FiO}_2$ . HFNC are always used with heated humidifiers. The delivered concentration and flow of oxygen affect the final  $\text{FiO}_2$  and they can be controlled independently in some devices. However, direct caregivers should be cautious that even with these devices, the  $\text{FiO}_2$  can be reduced if the inspiratory flow of an occasionally severe dyspnoeic patient exceeds the device's total flow output. With the emergence of the COVID-19 pandemic, the potential of HFNC as an alternative to standard oxygen therapy and non-invasive ventilation (NIV) has been revisited with special interest across the globe. Guy *et al.* in a monocentric study concluded that HFNC was effective in managing COVID-19 patients in an intensive care unit setting.<sup>7</sup> A study of moderate to severe COVID-19 patients by Geng *et al.* suggested that the administration of HFNC reduced the rate of intubation and improved the clinical outcome in type 1 acute respiratory failure.<sup>8</sup>

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## Physiological Humidification: Absolute and relative humidity

The importance of the upper airway is often understated. However, it holds special significance with regard to understanding the processes behind the physiological humidification of inspired air. Besides the upper airway, the trachea provides a counter current mechanism for heat and moisture exchange during breathing and hence plays an important role in heating and humidifying inspired gas.

Understanding the concept of humidity and the ways to measure it is beneficial in a discussion pertaining to the physiology of humidification of inspired gas.<sup>4</sup> Humidity is quantified in two ways; Absolute humidity (expressed in  $\text{g}/\text{m}^3$ ) defined as the mass of water vapour present per unit volume of gas at any given temperature and pressure.<sup>9</sup> Relative humidity (expressed as a percentage) is a comparative measurement describing the ratio between the mass of water vapour present in a given volume of air to the mass of water vapour required to completely saturate said volume of air at a particular temperature.<sup>4</sup>

The nose is the site of maximal heat and moisture exchange. A gradient of heat and absolute humidity is achieved down the upper airway.<sup>10</sup> The normal temperature, relative humidity and absolute humidity of inspired gas at the airway opening are about  $22^\circ\text{C}$ , 50% and  $10 \text{ g}/\text{m}^3$ , respectively. After normal heating and humidification mechanisms in the intact upper respiratory tract, these values reach  $29\text{--}32^\circ\text{C}$ , 95% and  $28\text{--}34 \text{ g}/\text{m}^3$  in the oropharynx and  $32\text{--}36^\circ\text{C}$ , 100% and  $34\text{--}40 \text{ g}/\text{m}^3$  in the trachea. On reaching the lungs, the inspired gas is fully saturated with water vapour at body temperature ( $37^\circ\text{C}$ , 100% relative humidity,  $44 \text{ g}/\text{m}^3$  absolute humidity).<sup>11</sup> The point at which this occurs is called the isothermic saturation boundary (ISB) which is approximately 5 cm distal to the carina at the level of the third generation airways.<sup>4</sup>

Nasal mucosa is kept warm and moist by secretions from goblet cells and mucous glands such that when inhaled air passes through the path created between the turbinates, incoming air is warmed by convection. Liquid moisture from the epithelial lining evaporates by utilising latent heat of vaporisation to add to the humidity of inhaled air. Heat and moisture exchange is crucial to maintaining mucociliary function as the ciliary motility is drastically reduced, airway irritation is increased and pulmonary secretions become viscid and inspissated when exposed to cold, dry air.<sup>12</sup> Respiratory heat loss occurs during exhalation as latent heat is released when water vapour from saturated exhaled air condenses in the upper airways.

Thus, the airways are prepared for another cycle of heating and humidification of inspired air.

## The Physics of Humidification

Humidifiers form an important part of oxygen delivery systems. A variety of devices are available to achieve ideal humidity levels that are as close to the physiological requirement as possible. Based on their mechanism of action, humidifiers are divided into active and passive types.<sup>9</sup> Active humidifiers such as bubble and pass-over humidifiers add water or heat or both to the inspired gas. Passive humidifiers such as heat and moisture exchangers (HME) for example, use exhaled heat and moisture to humidify inspired gas. A nebulizer produces an aerosol (a suspension of water particles in gas) for humidification.

Bubble humidifiers are one of the most common humidifiers used in developing countries such as India.<sup>13</sup> These are water containers in which gas is forced to escape through a tube placed at the bottom.<sup>14</sup> The gas bubbles collect moisture as they move towards the water surface and pass through an outlet connected to an oxygen delivery device. A number of factors govern the amount of water vapour gained through this process. Lower flow rates allow longer contact time between the gas and water thereby increasing humidity. The higher is the flow through a bubble humidifier, the lower the water vapour content and temperature of the gas leaving the device. Flow rates of more than  $10 \text{ L}/\text{min}$  usually result in decreased contact time and inability to achieve required absolute humidity.<sup>13</sup> The absence of a diffuser also lowers humidity. Diffusers break larger gas bubbles into smaller ones, increasing the surface area thus enabling greater gas-liquid interaction. Moreover, a heat source provides the latent heat of vaporisation required to maximize the humidification of gas.

More often than not, especially in resource-limited setups, there is an absence of a heat source. The resultant use of cold bubble humidification generates an absolute humidity of only  $10\text{--}20 \text{ g}/\text{m}^3$  at standard room temperature against the physiological requirements of at least  $34 \text{ g}/\text{m}^3$  in trachea and  $44 \text{ g}/\text{m}^3$  below carina at the ISB.<sup>13</sup> A comparison of various humidifiers shows that while cold bubble humidifiers and HMEs drastically fail to provide 100% saturation at  $37^\circ\text{C}$  and heated water baths just meet the requisite levels, heated nebulisers based on the Bernoulli-effect and ultrasonic nebulisers more than surpass the mark.<sup>13</sup>

## Infections Associated with Cold Bubble Humidifiers

Respiratory tract infections are the most common type of healthcare-associated infections (HAI).<sup>15</sup> Elderly, immunocompromised or critically ill subjects are particularly susceptible to the nosocomial infections caused by several bacteria and fungi. Equipment used for respiratory care such as nebulisers, ventilators and humidifiers may act as potential vehicles for transmission of those organisms, though their exact role in the causation of HAI is still a matter of debate. Humidifiers may serve as a reservoir of several microorganisms as the fluids inside them may be contaminated by different bacteria and fungi. Some of the organisms may also multiply in the stagnant water. The organisms gain access to the host in two ways: either from the aerosolisation in the room or through direct delivery to the airways.<sup>16</sup> Moreover, many gram-positive and gram-negative bacteria can form biofilms over medical devices; some of the important organisms among them are *Staphylococcus aureus*, *Enterococcus faecalis*, coagulase negative *Staphylococcus*, *Klebsiella pneumonia* and *Pseudomonas aeruginosa*.<sup>17</sup>

La Fauci *et al.* conducted a study by collecting water samples from disposable and reusable oxygen humidifiers from different wards and processed them for microbial analysis.<sup>18</sup> They found a very high rate of microbial contamination in samples from reusable oxygen humidifiers in comparison to the disposable ones. The contamination rate in the reusable oxygen humidifiers in emergency areas was more than 50% and the most relevant pathogens were *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Another hospital-based study conducted by Jadhav *et al.* showed that colonisation rates of the oxygen humidifier chambers of portable cylinders and pipelines by bacteria and fungi were 75% and 87% respectively.<sup>16</sup> *Aspergillus Spp.* was the most common among the fungal isolates. Among the gram negative bacteria, several multi-drug resistant organisms such as *Klebsiella pneumonia*, *Pseudomonas spp.*, *Acinetobacter spp.* and *Escherichia coli* were isolated.

## Recommendations

Jadhav *et al.* demonstrated the importance of disinfection, documenting reduced colonisation rates of 15% and 12% for fungi and bacteria, respectively, after maintenance of hand hygiene and disinfection of humidifier chambers with 70% ethanol.<sup>16</sup> Overall, it is recommended that sterile water be used instead of tap water along with regular and thorough cleaning and changing of humid-

ifiers to prevent microbial growth. However, with resources being stretched to a maximum, especially during the on-going pandemic, meticulous implementation of such practices may prove to be difficult. Hence, revisiting the rationale behind routine usage of humidified oxygen over 'dry' (without usual cold bubble humidification) oxygen is reasonable.

Non-humidified and non-heated air-oxygen mixtures can lead to increased airway resistance, dried up upper airway mucosa leading to reduced mucociliary clearance, airway mucosal inflammation and damage and an increase in the amount of energy expended by patients to warm and humidify the delivered gas.<sup>19</sup> Cold bubble humidifiers are unable to add the necessary amount of humidification and heat needed to prevent the above mentioned complications. Over the years, several studies have validated that there is little difference in clinical outcomes and symptom severity between patient groups using humidified and non-humidified oxygen.<sup>20,21</sup>

The British Thoracic Society guidelines do not recommend routine humidification of oxygen when delivered under low flow (1–4 L/min) unless upper airways are bypassed, as in intubated or tracheotomised patients.<sup>22</sup> Higher flows of oxygen (>4 L/min) can cause upper airway discomfort due to dryness, although most patients may be able to tolerate it. The maintenance of adequate hydration of all patients receiving supplemental oxygen remains most essential. The guidelines also suggest administering normal saline nebulisation for liquefying viscid secretions, further negating the requirement of oxygen humidification.<sup>22</sup>

Furthermore, high-flow oxygen therapy, if needed, should be provided with heated humidifiers as opposed to cold bubble humidifiers which are highly ineffective. Studies by Santana *et al.* and Franchini *et al.* support that finding that cold bubble humidifiers fail to provide any additional humidity to nasal mucosa when compared to non-humidified oxygen therapy.<sup>23,24</sup> Humidification of inspired oxygen can only be considered in patients who complain of excessive nasal dryness associated discomfort. However, topical application of water-based lubricants can be a reasonable solution to this complaint.<sup>4</sup> In published guidelines on oxygen therapy in paediatric patients, available evidence has not supported the use of heated or unheated humidification with low-flow oxygen delivery.<sup>25,26</sup>

## Conclusion

Warren Buffet once said, 'Chains of habit are too light to be felt until they are too heavy to be broken;'

in this context, it would be essential to consider the dangers of continuing the common practice of cold bubble humidification. With the growing need for oxygen administration due to COVID-19 infection, the importance of heating and humidification with oxygen administration should be reaffirmed. However, the issue is universal and not associated only with the current pandemic. In light of better technology, cold water humidifiers have been rendered redundant as they are unable to provide the adequate humidification required by the respiratory tract. Moreover, evidence suggests that humidification is not mandatory in patients on oxygen therapy with any of the low-flow delivery devices, as described earlier. Furthermore, it is imperative that cold bubble humidifiers are acknowledged as a breeding ground of infections, especially in resource-stretched facilities due to difficulty in regular cleaning and maintenance. Since cold bubble humidifiers are evidently unable to humidify to the levels required, it appears that its usage should be abandoned as it offers no significant added advantage over room air and also increases the potential for infection risk.

#### AUTHORS' CONTRIBUTIONS

SD and SG prepared the manuscript with adequate planning and execution. SD and AC contributed to the review of literature, critical revision of content and final approval of the manuscript. All authors agree to be accountable for all aspects of the work and ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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