Clinical Foundations

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High Flow Nasal Cannula

Meagan N. Dubosky, MS, RRT-ACCS, NPS, AE-C

Heated and humidified high-flow nasal cannula (HFNC) usage has gained popularity in the management of patients with moderate to severe hypoxemia. Capable of providing gas flow rates up to 60 LPM, HFNC therapy can potentially exceed the patient's inspiratory flow demands resulting in a fixed delivery of the desired fraction of inspired oxygen (FiO_2), ranging from 0.21 to 1.0. Its reported effectiveness and improved patient comfort warrants clinicians to understand how to apply and manage this oxygen therapy device. This article will explain the HFNC's evolution, potential mechanisms of action, use in various patient conditions, and suggest a recommended application and management.

Panel Discussion: High Flow Nasal Cannula: Opinions from the Experts

Moderator: *David Vines, PhD, RRT, FAARC*

Panelists: *Jonathan Waugh, PhD, RRT, FAARC*
Robert Joyner, PhD, RRT, FAARC
Ronny Otero, MD, FAAEM, FACEP

In this panel discussion, four experts convene to discuss topics such as the role and potential benefits or hazards with the use of HFNC in the management of acute hypoxemic respiratory failure, the role and potential benefits or hazards with the use of HFNC in acute exacerbation of COPD patients, the role of HFNC in the management of patients with chronic conditions in subacute or home care, improving patient comfort and tolerance with HFNC, weaning from HFNC, and whether or not the size of the bore of the HFNC makes a difference. A full list of references is included.

High Flow Nasal Cannula

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Introduction

Heated and humidified high-flow nasal cannula (HFNC) usage has gained popularity in the management of patients with moderate to severe hypoxemia. Capable of providing gas flow rates up to 60 LPM, HFNC therapy can potentially exceed the patient's inspiratory flow demands resulting in a fixed delivery of the desired fraction of inspired oxygen (FiO_2), ranging from 0.21 to 1.0.1-3 Its reported effectiveness and improved patient comfort warrants clinicians to understand how to apply and manage this oxygen therapy device.[4,5] This article will explain the HFNC's evolution, potential mechanisms of action, use in various patient conditions, and suggest a recommended application and management.

The Evolution of HFNC

Oxygen therapy has long been used in the treatment of hypoxemia and has evolved in the past two decades.[5] Low flow systems, capable of delivering 1-15 LPM, include the nasal cannula, simple mask and partial/nonrebreathing mask. These devices deliver a variable FiO_2 due to the delivered oxygen mixing with room air being inspired by the patient. The amount of delivered FiO_2 or effective inspiratory oxygen concentration (EIO_2) may vary breath to breath due to variations in patient breathing patterns and patient's peak inspiratory flow rates exceeding the flow delivered by the device.[1,5-7]

High flow systems, such as air entrainment masks, provide a more precise FiO_2 than low flow systems but have lower tolerance due to mask discomfort and inadequate heat and humidification.[5,8-10] This fixed FiO_2 is associated with lower FiO_2 settings. Generally speaking, a FiO_2 of 0.40 or higher is associated with an air entrainment ratio that may not meet a majority of patients' inspiratory flow demands. A HFNC system combines an air/oxygen blender with an active humidity system, allowing for independent control of temperature, FiO_2 and gas flow rates ranging from 2-8 LPM in infants and 16-60 LPM in adults.[1,5,11] When a gas flow rate is 60 LPM or higher the device is considered to deliver a fixed FiO_2 and this flow exceeds most patients' inspiratory flow demands.[11]

> The washout of expired CO_2 from anatomical dead space is thought to be one of the primary mechanisms contributing to the success of HFNC therapy.

First utilized in neonatal and pediatric respiratory care, HFNC is a first-line therapy in managing patients with respiratory distress syndrome, apnea of prematurity, hypoxic respiratory failure and hypoxemia post extubation.[5,12] With nasal prongs now tailored to fit adults, the potential advantages for those with dyspnea and hypoxemia have increased.[5,12,13]

Mechanisms of Action

Dead Space Washout

The washout of expired CO_2 from anatomical dead space is thought to be one of the primary mechanisms contributing to the success of HFNC therapy.[5,12,14] The reduction in fraction of inspired CO_2 allows for a larger amount of FiO_2 to participate in gas exchange and lower minute ventilation needs. This may result in a decreased respiratory rate and/or tidal volume, thus, less work of breathing (WOB). Data from multiple animal studies and clinical trials has shown a reduction in $PaCO_2$, tidal volume, minute ventilation, and dead space with use of HFNC.[12,13]

Metabolic Expenditures

Resting energy expenditure, an estimate of base metabolic rate, is increased in critically ill patients and those with abnormal pulmonary mechanics.[15] Decreasing the energy used by the respiratory muscles to breathe and the upper airway to condition inhaled gases may benefit those who are ill and in respiratory distress.

Variable resistance is created by the nasopharynx with more resistance created during the inspiratory phase than the expiratory phase. Patients with an increased respiratory rate spend more time working to overcome this inspiratory resistance. Traditionally CPAP was used to splint these airways open and normalize functional residual capacity (FRC), consequently, reducing the work load. It is likely that HFNC meets the flow demands of the patient and when the patient's mouth is closed, in turn decreasing energy used in resistive work of breathing.[16,17] Energy is also required to raise the temperature of room air and to vaporize water content creating gas conditions that are body temperature (37° C) and fully saturated at 100% relative humidity. The nasal passage heats and humidifies well under normal conditions, but is stressed when cold, dry medical gas is administered. This issue too is resolved with the use of heated and humidified HFNC.[5,12]

Gas Conditioning & Comfort

Another potential benefit of the heated and humidified gases being delivered is improved secretion clearance and patient comfort. Unconditioned medical gas administration moves the isothermic saturation boundary (ISB) further into the lower respiratory tract. This shift can damage ciliary function and dehydrate mucosal tissue creating retention of secretions. A bench study evaluating the effects of gas humidification on human airway epithelial cells found an increase in inflammatory markers following 8 hours of low humidity.[18] Aside from cellular damage, breathing cold, dry medical gas can lead to discomfort and pain. Numerous studies have provided subjective data stating that patients better tolerated HFNC when compared to other devices, including NIV.[1,5,12,13,19,20] Often times comfort leads to compliance and in patients refusing to wear conventional oxygen masks or NIV interfaces, the HFNC has been shown to be more comfortable. This is likely due to the less intrusive, soft nasal cannula delivering heated and humidified airflow.[21] Perceived comfort may also be directed related to the patient's ability to eat, drink and speak freely while on HFNC.

> Potential benefits consist of improved oxygenation, work of breathing, secretion clearance, patient tolerance as well as avoidance of intubation.

Flow Demands

As stated earlier the high flow provided by this device meets or exceeds the inspiratory flow demands of a patient allowing a more precise FiO_2 delivery.[22] Patients in respiratory distress often have inspiratory flow rates that exceed traditional low flow device outputs. Entrainment of room air occurs with all oxygen delivery devices, but is minimized with the HFNC, especially with closed-mouth breathing.[5]

Clinical Applications

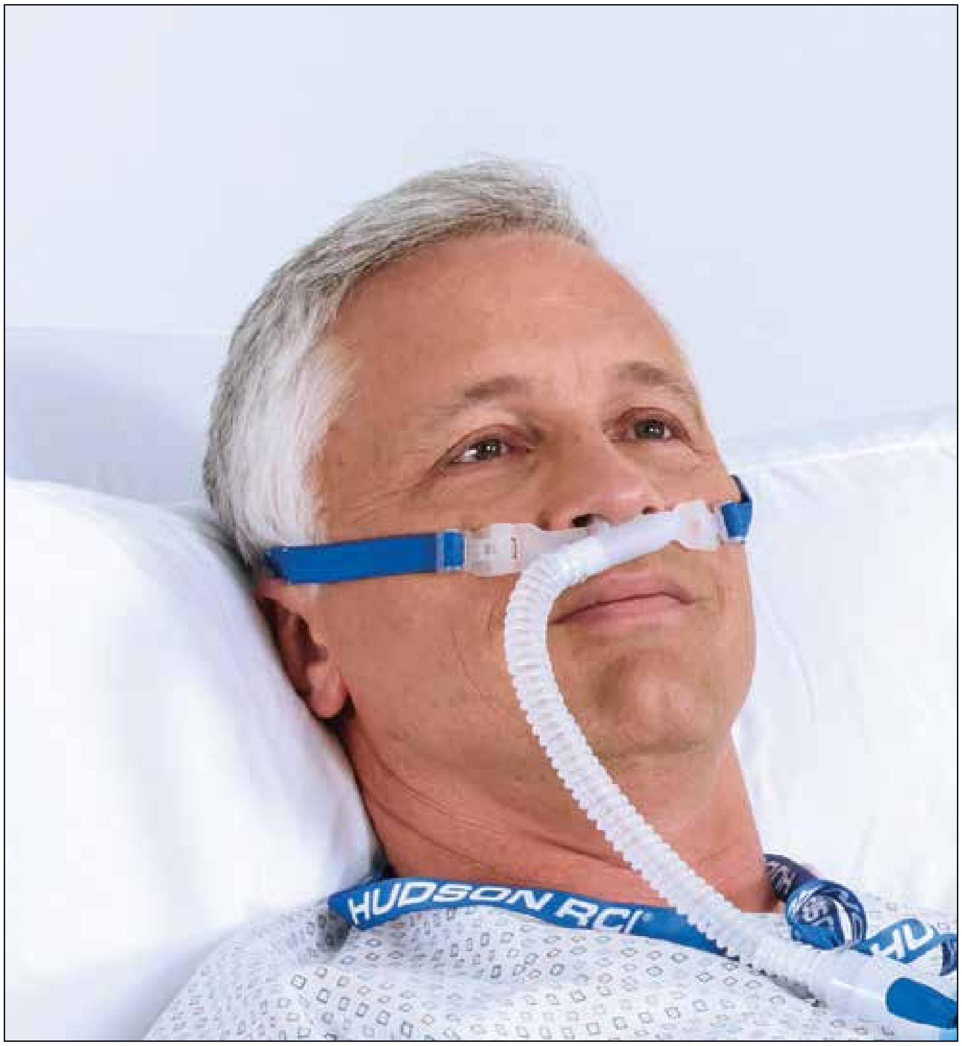
The main indication for use of HFNC is to support spontaneously breathing patients with high oxygen and/or flow requirements with moderate to severe hypoxemia and increased work of breath. Potential benefits consist of improved oxygenation, work of breathing, secretion clearance, patient tolerance as well as avoidance of intubation. Contraindications would include nasal passage abnormalities or recent nasal surgery, apnea, respiratory arrest and hypercapnic respiratory failure requiring mechanical ventilation.[10,12,13,23,24]

Acute Hypoxemic Respiratory Failure (AHRF)

Respiratory failure occurs when the lungs can no longer achieve gas exchange in a manner that is suitable to support life if left untreated. Hypoxemic respiratory failure (Type I) is a failure to oxygenate and ventilatory failure (Type II) presents with a rise in carbon dioxide and an inability to clear it.[1,25] Noninvasive ventilation (NIV) is a cornerstone treatment for those in Type II respiratory failure but data has lacked regarding NIV use in Type I or AHRF. Frat et al recently published back to back studies exploring HFNC in this population. The first clinical study (n=310) compared HFNC, standard oxygen and NIV in patients with AHRF, defined as a partial pressure of arterial oxygen to the fraction of inspired oxygen (P/F) of ≤ 300 mm Hg without hypercapnia. Intubated at day 28 was the primary outcome with all-cause mortality in the intensive care unit (ICU), 90-day mortality and ventilator free days at day 28 recorded as secondary outcomes. They found no significant difference in the primary outcome of 28 day intubation rates amongst the 3 devices, although the rate was higher in the NIV and standard oxygen groups. A difference was found favoring the HFNC in 90-day mortality. In a subgroup analysis, they did report a benefit in intubation rates in patients with P/F ratio of less than 200. The study team speculated that the lower mortality rate may have resulted from the overall effects of less intubation. It was reported that at 1-hour post study enrollment, subjective measures of discomfort and dyspnea were highly improved in the HFNC arm.[13] A more recent retrospective study with historic controls observed a significant reduction in invasive and noninvasive interventions in severe AHRF patients with the use of HFNC.[26]

Frat et al also explored the use of

HFNC alternating with NIV in AHRF, defined as a P/F ≤ 300 mm Hg with standard oxygen mask with an increased respiratory rate (> 30 breaths/min) or respiratory distress. Twenty-eight subjects were included and clinical efficacy was evaluated. They concluded that HFNC was better tolerated and resulted in improved oxygenation and tachypnea (mean PaO_2 from 83 to 108 mm Hg). Although oxygenation with NIV (mean PaO_2 from 83 to 125 mm Hg) did improve more dramatically, the improved tolerance with HFNC might serve as an alternative.[23,25]



High Flow Nasal Cannula (Courtesy of Teleflex)

Post Cardiothoracic Surgery

NIV is commonly used to prevent reintubation in hypoxemic patients following cardiothoracic surgery. Moderate evidence (grade 2) supports the practice of NIV following cardiac or thoracic surgery to correct hypoxemia and stave off reintubation, although approximately 20% fail and still require reintubation. Stephan and colleagues devised a multicenter, randomized, noninferiority trial (n=830) hypothesizing that HFNC was not inferior to NIV for prevention or resolution of AHRF following surgery. Measured outcomes were frequency of treatment failure (primary) and changes in respiratory variables and complications (secondary). Enrollment occurred at the time of a failed spontaneous breathing trial or when extubation failed. The outcomes support HFNC use in these patients as there was no difference in treatment failure or ICU mortality. Skin breakdown in patients receiving BiPAP treatment was significantly greater than those treated with HFNC ($p < .001$).[27]

Intubation and Post Extubation

Intubation and extubation involves moments where the airway is occluded and oxygen delivery is interrupted. Tracheal intubation is a common procedure in the ICU and is often association with hypoxemic complications. Pre-oxygenation is routine practice but often neglected when a patient becomes so unstable that airway protection is at risk. Romain et al compared preoxygenation with a nonrebreather (NRB) to HFNC during direct larygoscopy in the ICU (n=101). The use of HFNC when pre-oxygenating significantly decreased severe hypoxemia when compared with NRB during intubation. The ability to leave the device in place throughout the entire procedure potentially increased the oxygen delivery delaying desaturation.[28]

Post extubation use of HFNC has increased in recent years. When compared to a NRB mask in a retrospective analysis (n=67) it was found that P/F improved in the HFNC group as well as more ventilator-free days ($p < 0.05$). Potential benefits supporting HFNC success in this population were the maintenance of mucosal function preserved by heat and humidity. Patient tolerance may have been achieved with the ability to speak and eat while on the HFNC device.[23]

Do-Not-Intubate

Noninvasive ventilation is commonly used in patients at the end of life with a do-not-intubate (DNI) directive. The respiratory insufficiencies in this population have traditionally been supported with a face mask and NIV, however, there was often difficulty with mask fit and tolerance. The Mayo Clinic assessed the effectiveness of HFNC in hypoxemic DNI patients (n=50) with mild hypercapnia ($PaCO_2$

< 65). Nine (18%) of the 50 subjects escalated to NIV, which was the primary endpoint. The other 82% were maintained on HFNC for a median duration of 30 hours. HFNC was found to provide acceptable oxygenation and may be considered as an alternative to NIV in DNI patients.[20]

Heart Failure

Heart failure (HF) is a common cause of AHRF and is associated with poor outcomes. Patients with HF often have issues oxygenating with conventional oxygen therapy leading to use of NIV and potential intubation. Not only do these rescue therapies with positive pressure improve oxygenation, they also increase intrathoracic pressure reducing the work of breathing and decreasing preload, each of these being highly beneficial in HF.

Roca and colleagues hypothesized that the level of pressure created with HFNC delivery would decrease preload in HF without changing cardiac output. They enrolled stable NYHA class III heart failure patients (n=10) with an ejection fraction of < 45%. Air (FiO_2)[21] was delivered to these patients via HFNC while the inferior vena cava (IVC) was measured via transthoracic echocardiography (TEE). Inspiratory collapse of the IVC was used as a surrogate for preload and was measured while HFNC was delivered at different flow rates. Inspiratory collapse was significant with baseline (no flow) at 37% collapse, HFNC (20 LPM) was 29% and HFNC (40 LPM) was 21%. The increase in HFNC flow appeared to correlate with an increase in intrathoracic pressure and decrease in inspiratory collapse of the IVC. Also found was that respiratory rates significantly reduced and no other clinical changes were noted. It was concluded that NYHA class III heart failure patients might benefit from HFNC treatment.[30]

> Patients with HF often have issues oxygenating with conventional oxygen therapy leading to use of NIV and potential intubation.

COPD

Many of the mechanisms of action previously reviewed regarding HFNC could potentially benefit COPD patients. The "go-to" treatment in this disorder is NIV, but treatment intolerance and mask discomfort are well documented. Potential benefits of HFNC include the increase in pressure and decrease in respiratory rate with high flow rates helping to support inspiratory efforts. The elevated positive expiratory pressures may splint open the airways allowing a lower FRC similar to the effect associated with pursed lipped breathing. This support could lower the work of breathing while the higher flow rates wash out of CO_2 from dead space.[31] Of note is the fact that FiO_2 can be manipulated with HFNC therapy making the device an option to deliver low FiO_2 and high flows to COPD patients.

Delivery Techniques

Clinical data for the application of HFNC in the adult population is increasing, but there is still a lack of formal recommendations for usage. Physiologic response to flow and FiO_2 are evident in animal and human studies and these are the two parameters that are adjusted. Flow rates in published studies have started at 30 LPM up to 50 LPM.[5,13,29,33] One could start at a flow rate of 30 LPM and that is titrated in response to the patient's respiratory rate and work of breathing. This initial flow rate is usually increased to 50 LPM if tolerated by the patient and observed respiratory distress lessens. Unless they have COPD, the FiO_2 is started at 1.0 and adjusted to maintain a target saturation of 92-98%. Patients with COPD start at FiO_2 of 50% or less and then adjusted FiO_2 to a target saturation of 90-92%. Further study is needed for full validation.

Nasal prong sizing is an important aspect and manufacturer guidelines and sizing tools should be followed. Typically, the nasal cannula prong diameter should be approximately half the size of the patient's nostril for adequate delivery.

Patients receiving HFNC should be assessed often for comfort and physiologic response in the form of heart rate, respiratory rate, breath sounds and SpO_2. Flow and FiO_2 should be monitored on the device as well as patency of the circuit and cannula with both being change when visibly soiled.

Conclusion

Use of HFNC in the adult patient population continues to evolve. With respiratory distress and hypoxemia being a common issue in the clinical setting, the HFNC is a welcome addition to the arsenal of noninvasive strategies. Patient tolerance is pivotal in the increased usage and this is likely due to the small size of the interface and the heated and humidified gas. Clinicians also find the interface easy to maneuver during procedures such as intubation and extubation, providing a continual source of oxygen and dead space washout. Comprehensive strategies for use will need to be further developed as the data from clinical trials increases.

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Panel Discussion

High Flow Nasal Cannula: Opinions from the Experts

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Ronny Otero, MD, FAAEM, FACEP

What is the role and potential benefits or hazards with the use of HFNC in the management of acute hypoxemic respiratory failure?

Otero: I believe that the role of Heated Humidified High-Flow Nasal Cannula (HFNC) is still growing. As a practitioner of emergency medicine where a large portion of my practice includes patients with COPD, diffuse parenchymal lung disease and decompensated heart failure we are always looking for other options in managing a patient's respiratory decompensation. We are challenged by the acuity of a patient's presentation and must resist the temptation to resort to rapidly intubate and initiate mechanical ventilation. HFNC provides us with an option to treat hypoxemic respiratory failure that does not respond to conventional oxygen therapy. A recent study shows a rapid improvement in a patient's perceived dyspnea in the emergency department (ED) when HFNC is applied early.[1] Support for this approach can also be found in the recent FLORALI trial which compared standard oxygen therapy vs HFNC vs noninvasive ventilation. In this study there was no difference in intubation rate between these therapies but a statistically significant increase in ventilator free days and 90-day mortality for patients treated with HFNC. What is also interesting is that the majority of the patients in the study had some form of pneumonia in all three treatment groups.

The hazards with the use of HFNC is improper patient selection. Practitioners should probably avoid using HFNC in patients with moderate to severe hypercarbia, acute hypoxemic respiratory failure with other organ failure and definitely should be avoided in patients with nasal anatomic abnormalities which would preclude use of nasal prongs and also the presence of a pneumothorax. [3]

Waugh: While some consider HFNC to be anything greater than the upper end of the typical flow rate delivered by "traditional" nasal cannula (depending on the patient size), most clinicians would describe it as delivering a constant flow rate typically greater than the patient's average spontaneous peak inspiratory flow. High flow therapy (HFT) via nasal cannula (ideally BTPS or greater) has a therapeutic effect independent of supplemental oxygen. HFNC can improve oxygenation by flushing some of the exhaled gas in the anatomic dead space and replacing it with oxygen-enriched gas, provided the flow rate is high enough. This is somewhat analogous to how tracheal gas insufflation flushes the tracheal dead space. Purging CO_2 from the airway and replacing it with oxygen-enriched gas provides a greater alveolar oxygen concentration at whatever FIO_2 setting is used. HFNC is susceptible to the same hazard that all therapeutics have—failure to recognize that the patient requires different therapy in a timely fashion.

Spontaneously breathing patients with high oxygen requirements are usually candidates for HFNC. Many clinicians substitute HFNC when a nonrebreather mask (NRB) would otherwise be used. One of the earliest HFNC clinical reports described that CHF patients in the emergency room had higher oxygen saturations with a HFNC at 20 LPM compared to NRB.[4] Acute hypoxemic respiratory failure can lead to ventilatory failure and just as noninvasive ventilation (NIV) is often used to avoid invasive ventilation, HFNC may be a way to avoid both types of mechanical ventilation, if appropriate. A recently published multi-center, open label trial (n=310) in the New England Journal of Medicine found a statistically insignificant decrease in intubation rate for HFNC compared to standard oxygen therapy by mask and NIV but a significant difference in favor of HFNC for 90-day mortality.[2] In clinical reports by

Taft (n=61) and Sarkisian-Donovan (n=29), patients had pre-HFT mean oxygen saturations of 88% and respiratory rates of 25 bpm or greater and all were able to avoid mechanical ventilation.[5,6] Rojas et al (n=377) reported a 51% decrease in the use of mechanical ventilation, with a 97.3% decrease in nasal continuous positive airway pressure (CPAP).[7] Sreenan et al, found HFNC as effective as nasal CPAP[8] for treating apnea of prematurity and Martinez-Gomez reported increased success with infant extubations.

HFNC is more comfortable for most patients because it contacts and covers much less of the face than modalities requiring a mask of some type. It does not require pressure on the skin or nasal mucosa to have its effect. Greater comfort translates to greater compliance with therapy.

Joyner: The high flow nasal cannula (HFNC) is a wide-bore nasal cannula that can provide a patient with heated and humidified oxygen at a concentration up to 100% and flow rates up to 60 LPM.[9] Determining if a HFNC is appropriate in the care of patients with acute hypoxemic respiratory failure requires the practitioner to have knowledge of the physiology causing the hypoxemia. Research trials to date are conflicting and seem to suggest that a subset of patients with acute hypoxemic respiratory failure may benefit from HFNC, but seem to also suggest not all patients will benefit and some may be harmed. Timing and length of delivery prior to intubation is an important factor.

A retrospective study by Kang et al., enrolled patients who failed a trial of HFNC prior to intubation.[10] The patients were divided into two groups: patients that received HFNC for less than 48 hours and patients that received HFNC for longer than 48 hours prior to intubation. Those patients who were maintained on HFNC for greater than 48 hours had higher ICU mortality, higher extubation failure, and fewer ventilator free days. This suggests that prolonged use of HFNC may delay more appropriate care of the patient.

In another study by Corley et al., HFNC was shown not to improve atelectasis, oxygenation, respiratory rate, or dyspnea compared to standard oxygen therapy in obese patients following cardiac surgery.[11]

Not all trials have been negative, but the more positive trials seem to have enrolled patients less acutely ill than patients defined as being in acute hypoxemic respiratory failure. For example HFNC has been shown to improve comfort and oxygenation and reduce rates of intubation when compared to the venti-masks.[12] The evolution of the HFNC is reminiscent of the path noninvasive ventilation took 20 years ago. When non-invasive ventilation was just coming out there was tremendous enthusiasm for its ubiquitous use.[13] Ultimately it was shown to have its place with a select patient population (e.g., exacerbations of COPD) and not as successful with other populations (e.g., severe community acquired pneumonia).[14]

What is the role and potential benefits or hazards with the use of HFNC in acute exacerbation of COPD patients?

Otero: Based upon its purported assistance with mucociliary clearance which is partially explained by the high level of humidification its use in COPD may have some theoretical benefit. If a COPD patient is hypoxic the ability of HFNC to create nasopharygeal wash-out will provide an oxygen source that may be missing when only nasal cannula is applied. It is however difficult to transpose the findings of studies examining hypoxemic respiratory failure which have shown an improvement in dyspnea and respiratory rate to a COPD population.[15] The literature is still growing but as of yet there are few articles which have been able to demonstrate long-term improvements.

Waugh: COPD presents the challenge of a mixture of pathologies to address including altered airway function, abnormal secretions, weakened respiratory muscle function and impaired gas exchange. HFNC has the potential to treat several of these anomalies. The importance of warming and humidifying inspired gas is well established.[16-20] Breathing cool, dry gases can produce deleterious effects such as mucosal damage, reduced ciliary motility, decreased mucus production, bronchospasm, and nasal discomfort and bleeding.[21] Delivering cool, dry gases via an artificial airway can magnify the negative impact of ventilation with consequences such as retained secretions, mucus plugging, atelectasis, increased work of breathing, hypoxemia, and hypothermia.[22] A protective or even therapeutic effect from inhaling warm, humidified gas is also possible.[23] Retained secretions are thinned and more easily expectorated and heated humidification has been shown to reduce or eliminate episodes of nocturnal asthma and exercise-induced asthma.[24] These benefits can be observed without using supplemental oxygen.

The high flow generated by HFNC effectually reduces or eliminates the felt inspiratory resistance caused by gas passing through the turbinates, reducing WOB for the patient. That same mechanism plus high flow washes CO_2 from the upper airway thereby aiding in CO_2 removal. The CO_2 removal increases the efficiency of ventilation which treats acute exacerbation of CO_2 retention and can allow mechanical ventilation to be avoided.

Joyner: HFNC represents an alternative for patients who have difficulty tolerating the mask interface required for non-invasive ventilation. At least one author has recently shown patients with stable COPD can be maintained and even thrive on HFNC in place of non-invasive ventilation.[25] Few clinical studies addressing the use of HFNC in hypercapnic respiratory failure have been conducted.[26] While this is an area ripe for research the need to facilitate carbon dioxide clearance by supporting minute ventilation may limit the usefulness of HFNC in this patient population.

Does HFNC have a role in the management of patients with chronic conditions in subacute or home care?

Otero: I think this a potentially growing indication particularly in specific patient populations. There is some literature to support its use in patients with pulmonary fibrosis and even with neuromuscular disease. Overall, there is very little long-term data.[27,28]

Waugh: The previously described mechanisms can be applied to help many chronic pulmonary patients. Gaylord Hospital, a Long Term Care Hospital in Wallingford, CT, reported thinner patient secretions and elimination of tracheostomy tube plugging (http://www.vtherm.com/gaylord-hospital/). In a comparison of 59 patients before a Vapotherm HFNC device and 157 afterward, the average time on ventilator dropped from 21 to 11 days.

Joyner: The sustained use of a HFNC requires a large bulk oxygen source that can be applied at high pressures (i.e., standard 50 psi outlet). In the hospital setting, essentially the oxygen source is unlimited and therefore not a needed consideration. In the subacute and home settings without bulk oxygen availability at best the use of a HFNC would have a limited time that it could be applied. In addition, if a HFNC was needed acutely to support oxygenation the clinician would need to determine if the acute event necessitates the movement of a patient to an acute hospital environment to receive appropriate care.

How would you recommend initiating HFNC in your institution, please include initial FIO_2 and flow settings?

Otero: When initiating HFNC in an institution it is first prudent to educate respiratory practitioners and clinicians about the appropriate indications for HFNC. It is important to emphasize that HFNC is not designed to replace non-invasive ventilation but as an adjunct for hypoxemic patients. Once this is clarified, it is generally recommended to start HFNC by setting the flow first to closely match a patient's minute ventilation before titrating the FIO_2. In adults, we usually begin flow rate at about 25-30 LPM and titrate FIO_2 to an spO_2 of ~90%. By the time we have considered HFNC the patient has already been on an FIO_2 of 35-50% so we rarely start a patient on an $FIO_2 < 40\%$. The initial flow and FIO_2 will vary from patient to patient. Our respiratory therapists have become familiar with many of our patients and have a good idea at what flow rate to initiate a patient.

Waugh: HFT can be accomplished in many adults at a flow rate around 25 LPM though some seem to benefit from higher flow rates. In NICU, starting flow rates are generally 4-6 LPM and children are 10-12 LPM. Vital signs and degree of labored breathing are assessed before and after starting therapy and monitored for improvement. If you do not see improvement, increase flow by 3-5 LPM and re-evaluate. This is repeated until improvement is seen. The patient will often verbalize when therapy is working. FIO_2 is adjusted to achieve the desired SPO_2 Starting high and weaning quickly works well.

Joyner: My suggestion would be to initially provide the patient with a sufficient FIO_2 to maintain a SPO_2 of at least 90%. I would begin by delivering a flow of 40 LPM and adjust the FIO_2 to obtain the saturation being sought. The flow being delivered to the patient should be guided by patient tolerance with meeting the patient's inspiratory demand being the goal. Once the patient is stable, guidelines from professional organizations for specific disease states can be utilized to provide the best state of the science care for the patient. For example the American Heart Association now suggests patients who are receiving therapy for an acute myocardial infarction should be supported with oxygen to an SPO_2 of approximately 94%.[29] In patients with COPD the GOLD guidelines suggest maintaining SPO_2 of at least 90%.[30]

What can be done to improve patient comfort and tolerance with HFNC?

Otero: In general, patients tolerate HFNC fairly well and usually better than noninvasive ventilation, perhaps due to the humidification. In the rare case where a patient is anxious (and not critically hypoxemic) anxiolysis can be prescribed. In my area, clinicians have become comfortable ordering dexmedetomidine. It is a $\alpha2$ adrenergic agonist. This means that it upregulates the inhibitory action of the $\alpha2$ receptor which decreases sympathetic outflow with the effect that patients will be in a calm state but still possess protective airway reflexes. Caution must be used in hypotensive patients when using dexmedetomidine as it can cause a sudden drop in blood pressure. This risk can be decreased by avoiding a bolus of the medication and starting a continuous drip.

Waugh: HFNC is typically well-tolerated and the most common "potential" problem seems to be when condensation is allowed to form inside the tubing (ensuring a minimum circuit temperature of 34 degrees F helps prevent this). Allowing the patient to wear the cannula for a few minutes prior to connecting the cannula can help avoid condensation in the cannula at initial connection. This allows the cannula tubing to be warmed by the patient's body heat through skin contact. Additionally, waiting for the HFNC circuit to warm (at least 34 degrees) prior to connecting the patient can help with comfort and prevent condensation.

Joyner: Assuring the straps securing the cannula are not overly tightened or crossing over a sensitive area (e.g., ears or areas of skin breakdown) is important. Providing the highest flow tolerated but not exceeding that rate is important to assure delivery of an accurate FIO_2. Periodic evaluation of cannula placement and strap tension should be done as some patients' needs can vary quickly with fluid resuscitation or the use of diuretics.

Describe how you would recommend weaning from HFNC?

Otero: Similarly to when we initiate High flow NC we wish to titrate our FIO_2 down to approximately 40%. We will reduced flow to 20-30 LPM. After this we transition to nasal cannula.

Waugh: Generally wean the FIO_2 first and then flow. Once you reach 35-40% O_2 concentration, begin weaning flow. Wean by 3–5 LPM and watch for signs of increased WOB. Continue weaning flow as tolerated to approximately 12–15 LPM. At 12–15 LPM and 35–40% most patients can go to a traditional nasal cannula (2–3 LPM of 100% oxygen). Once flow rate drops within the range of a traditional nasal cannula it is only a humidified cannula and not delivering HFT.

Joyner: Weaning a HFNC should be done through assessing the need for supplemental oxygen. Weaning the FIO_2 should be done dynamically as the patient is able to maintain their oxygenation status in the context of the reduction in the supplemental oxygen provided.

Does the size of the bore of the HFNC make a difference, why or why not?

Otero: Presumably we are talking about the bore of tubing delivering the oxygen to the nasal prongs? By Poiseuille's Law, the flow is going to be inversely proportional to the radius by a power of 4. The resistance to flow will be directly proportional to length and viscosity of fluid. Thus, a larger bore tube will decrease the resistance to flow of gas flowing to the nasal prongs and subsequently to patient's nasopharynx.

Waugh: The HF cannula bore size is important for at least two reasons. As previously discussed, it is desirable to avoid a snug fit of the cannula prongs in the patient's nares. A study by Frizzola et al, using piglets showed that the desired O_2 and CO_2 was obtained at lower flow rates when the nares were less obstructed by HFNC prongs. This allows greater flushing of the upper airway dead space with less end-expiratory distending pressure. Some devices use only one prong to maximize the opportunity for flushing of the upper airway.

It is important to generate sufficient flow to flush airway dead space and narrowing the internal diameter increases the flow at the tip of the cannula prongs. This jet flow must be at near BTPS conditions so that the flow remains comfortable. Narrowing the internal bore of the cannula increases resistance which in turn raises pressure in the circuit so the system must be designed to deliver sufficient flow as resistance increases. Small infants tend to be the greatest challenge for maintaining a combination of sufficient jet flow and adequate leak for flushing the airways.

Joyner: Within an acceptable tolerance I do not believe the bore size should matter. However if the flow is very high and the bore size is small the gas coming out of the cannula will come out at a high pressure and likely be uncomfortable for the patient. At the opposite end of the spectrum a bore size large enough to approximate the diameter of the patient's nare may intermittently create a seal and prove to be irritating as well. Anecdotally it seems that a bore size approximately one-half to three-quarters the size of the patient's nare diameter is best.

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Questions

1. **Heated and humidified high-flow nasal cannula (HFNC) can deliver a fraction of inspired oxygen (FiO_2) ranging from 0.21 to 1.0?**
   A. True
   B. False

2. **Which of the following are reasons that low flow oxygen devices deliver a variable FiO_2?**
   A. Oxygen from the low flow device mixes with room air.
   B. Patient's breathing patterns vary breath to breath.
   C. Patient's inspiratory flow rates exceed the flow delivered by the low flow device.
   D. All of the above.

3. **What is the range of gas flow rates that may be delivered with common adult HFNC systems?**
   A. 2-8 LPM
   B. 8-15 LPM
   C. 16-40 LPM
   D. 16-60 LPM

4. **The washout of expired CO_2 from anatomical dead space is thought to be one of the primary mechanisms contributing to the success of HFNC therapy.**
   A. True
   B. False

5. **Unconditioned medical gas administration moves the isothermic saturation boundary (ISB) to where?**
   A. Higher in the nasal passage
   B. The vocal cords
   C. Further into the lower respiratory tract
   D. The diaphragm

6. **Data from multiple animal studies and clinical trials has shown a reduction in $PaCO_2$, tidal volume, minute ventilation, and dead space with use of HFNC.**
   A. True
   B. False

7. **Non-invasive ventilation (NIV) has documented treatment intolerance due to the following reason(s)?**
   A. Mask discomfort
   B. Patient inability to speak, eat or drink
   C. Gases delivered are not optimally conditioned
   D. All of the above

8. **Respiratory failure occuring with an inability to clear carbon dioxide is know as this type of failure?**
   A. Type I
   B. Type II

9. **What settings can be adjusted independently when using a HFNC system?**
   A. Flow, Saturation, Temperature
   B. Flow, FiO_2, Temperature
   C. Flow, FiO_2, Saturation
   D. FiO_2, P/F ratio, Saturation

10. **Nasal prong sizing typically requires the prong diameter should cover approximately how much of the patient's nostril for adequate delivery?**
    A. 1/4 the size of the nostril
    B. 1/2 the size of the nostril
    C. 3/4 the size of the nostril
    D. The prongs should fit the nostrils snuggly

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Objectives

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

1. Explain the potential mechanisms of action of HFNC.

   Strongly Agree — Strongly Disagree
   1 2 3 4 5 6

2. Discuss HFNC use in various patient conditions.

   Strongly Agree — Strongly Disagree
   1 2 3 4 5 6

3. Describe the recommended application and management of HFNC.

   Strongly Agree — Strongly Disagree
   1 2 3 4 5 6

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

   Strongly Agree — Strongly Disagree
   1 2 3 4 5 6

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4	☐	☐	☐	☐
5	☐	☐	☐	☐
6	☐	☐	☐	☐
7	☐	☐	☐	☐
8	☐	☐	☐	☐
9	☐	☐	☐	☐
10	☐	☐	☐	☐

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