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High-flow nasal oxygen therapy

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Key points

- High-flow nasal oxygen therapy (HFNOT) provides a valuable triad of humidity, high F_{IO_2}, and improved patient compliance.
- It reduces heat and moisture loss from the airway, reduces anatomical dead space, provides PEEP, and improves oxygenation.
- There is increasing evidence for its use in acute respiratory failure, as an aid to preoxygenation, in the management of the difficult airway and during bronchoscopy.
- HFNOT can be useful in preventing postoperative respiratory failure.
- Cautions for its use are similar to those for non-invasive facemask positive pressure ventilation.

High-flow nasal oxygen therapy (HFNOT) is increasingly used as part of both ward-based and critical care management of respiratory failure. Respiratory failure is distressing for patients and treatment modalities currently in use may be associated with discomfort from upper airway drying, tightly fitting facemasks, and resultant complications such as skin breakdown. Invasive ventilation is also associated with a number of complications including ventilator-associated pneumonia.

The ability of nasal cannulae to provide positive pressure to the airways was first noted in neonates, and it is in this patient group that this therapeutic effect was first used. A similar continuous positive airway pressure (CPAP) effect, with higher flows, was noted in adults[1] and from here, HFNOT was developed.[2] HFNOT provides warmed, humidified gases at flows of up to 60 litre min^{-1}, with inspired oxygen concentrations of up to 100%. The use of HFNOT is well validated in neonatal populations and the body of evidence for its use in adults is rapidly growing.

Equipment

There are several different devices available for the provision of high flow, humidified oxygen via nasal cannulae. The devices consist of nasal cannulae with standard sized or wide-bore prongs connected to an oxygen flow meter with an air–oxygen gas blender and gas analyser. They offer maximum gas flow rates of between 40 and 60 litre min^{-1}, depending on the device. A heating system and humidifier allows delivery of gases at temperatures of between 33 and 43°C and 95–100% humidity (Table 1).

There are a number of different commercially available HFNOT sets. Some patient interfaces have soft contoured wide-bore nasal prongs designed to reduce gas jetting, while others are used with traditional narrow-bore nasal cannula. Wide-bore cannulae are worn with an adjustable head strap with quick release catch. An attachment for use with tracheostomy tubes is available. The interfaces are intended for single patient use with a maximum duration of use of 30 days.

Some devices have a water jacket delivery system surrounding the breathing circuit to provide insulation, while others provide warmed breathable tubing to reduce condensation build up. Inspiratory limb connections are 15 or 22 mm. They are latex-free and have a maximum resistance to flow of 11.6 cm H_2O. An aerosol adapter can be attached between the nasal cannulae and delivery tubing circuit to allow administration of nebulized drugs (Figs 1 and 2).

Humidity is provided by a disposable vapour transfer cartridge, a bubble humidifier, or a heated plate humidifier.[3] The vapour transfer cartridge is a patented device that surrounds the gas flow. Water diffuses through the cartridge, is heated, and passes into the gas flow as vapour. The bubble humidifier used in high-flow nasal oxygen delivery systems has been designed

Table 1 Comparison of the flow rate, relative humidity, and temperature of gas supplied by some commercially available HFNOT devices

Device tradename	Flow rate (litre min^{-1})	Relative humidity (%)	Gas temperature (°C)
Standard nasal cannula	1–4	Not humidified	Not warmed
Salter adult high flow cannula 1600HF™	15	Not humidified	Not warmed
Vapotherm precision 2000i high flow therapy™	5–40	95–100	33–43
Fisher and Paykel optiflow high flow nasal cannula™	1–60	100	37

Fig 1 Optiflow brand HFNOT set up on a mannequin. Would this patient be receiving significant PEEP?

for use at higher flows than a traditional bubble humidifier. Gas is directed into a water bottle where small bubbles are formed. These gain humidity as they increase to the surface of the water. The heated plate humidifier has a single-use water chamber over which gas flows and is humidified up to 100% relative humidity.

Physiological basis for the use of HFNOT

In health, quiet breathing generates gas flows in the region of 15 litre min^{-1} and this air is warmed and humidified in the upper airway. During nose breathing, this occurs through the evaporation of water from the nasal mucosa, with an increased surface area for this provided by the nasal turbinates. Gases reach a temperature of 36°C and humidification of 80–90% during passage through the upper airway. Inhalation of air through the mouth, however, reduces the maximum achievable relative humidity to 70%.

During exercise or respiratory distress, flow rates of up to 120 litre min^{-1} can be reached. This results in increased fluid losses and a higher metabolic oxygen requirement to achieve warmed gases. Flow rates such as this are achievable for only short periods of time and limited by fatigue. The application of cold, dry gases to patients with an increased oxygen requirement may exacerbate the heat loss and is associated with discomfort and reduced compliance with therapy. When this occurs, gas

Fig 2 Optiflow brand equipment detail, including humidifier, flow meter, stand, gas supply, and tubing.

Table 2 Summary of the physiological benefits provided by each feature of HFNOT delivery systems

Feature of HFNOT	Physiological effect
Warmed humidified gas	Reduced airway surface dehydration Improved secretion clearance Decreased atelectasis
Gas flow of up to 60 litre min^{-1}	CO_2 washout, reduction in anatomical dead space Provides an oxygen reservoir Allows F_{IO_2} close to 1.0 to be delivered
PEEP	Increased end-expiratory lung volume Alveolar recruitment

humidification decreases below 50% of relative humidity which can result in drying of secretions, reduced cilial function, and poor mucous flow.[4] This may lead to mucus plugging with resultant airway obstruction and arterial oxygen desaturation. Additionally, poor mucus flow predisposes to respiratory tree infection. Table 2 summarizes the physiological benefits of HFNOT.

Humidification and warming

Humidification and warming devices are available for facemask therapy but not widely used with nasal cannulae therapy. Conversely, HFNOT provides effective humidification and warming of gases, which allows more effective clearance of secretions, decreases atelectasis, and prevents airway surface dehydration.[4] It has been demonstrated that patients with acute hypoxaemic respiratory failure experience improved comfort and tolerance with HFNOT compared with humidified oxygen via a facemask, and traditional non-invasive ventilation masks.[5] Subjective feelings of dyspnoea and respiratory rates are reduced as is airway dryness.[6] Sensations of neck discomfort and gas flow being too warm have been rarely reported. This can be avoided by commencing HFNOT at lower flows and gradually increasing the temperature of the inspired gases. In our experience, commencing therapy at 25 litre min^{-1} and 31°C for the first 15 min improves patient compliance to increasing flows and temperatures. We recommend titrating gas temperature to between 34 and 37°C within the initial 30 min of therapy. This ensures that the important therapeutic benefit of humidified inspiratory gases is conferred early. Optimizing patient comfort is vital in the treatment of respiratory failure, not only to improve patient experience but also reduce rates of failed non-invasive ventilatory support and complications from intubation.

Delivery of high inspired oxygen fraction

Conventional oxygen delivery devices can deliver cold, dry gases at up to 15 litre min^{-1}, thus entrainment of air will limit the fraction of inspired oxygen (F_{IO_2}) that is possible to deliver with these devices. HFNOT by virtue of its ability to match higher inspiratory gas flows allows a higher F_{IO_2} delivery of up to 1.0 in moderate respiratory distress. Measured nasopharyngeal F_{IO_2} values correspond closely to the F_{IO_2} set on the device, unless the patient is grossly tachypnoeic.[7]

Dead space and PEEP

HFNOT provides an anatomical oxygen reservoir within the nasopharynx and oropharynx, by virtue of a CO_2 washout effect due to high oxygen flow. This reduces dead space[6] and in turn, work of breathing. There is also a CPAP effect[3] which provides an upper airway distending pressure of 3.2–7.4 cm H_2O with the mouth closed.[8] This results in positive airway pressure, increased end-expiratory lung volume, and thus alveolar recruitment, an effect that may be larger in patients with a higher body mass index. The distending pressure is transmitted to the lower airways to generate PEEP. It is, however, dependent to some extent on closed mouth breathing, and therefore, the PEEP generated is variable. The splinting of the upper airway that occurs due to this also has the effect of reducing airflow resistance in the nasopharynx, thus reducing work of breathing.

Clinical indications

The initial rationale for the use of HFNOT in neonates was to provide a distending pressure to counteract a lack of surfactant. Its use in neonates is now widespread and is backed by a large evidence base.[3] In adults, HFNOT is gaining popularity in the treatment of acute respiratory failure (ARF), in the management of difficult airways, to improve gas exchange post-abdominal and cardiac surgery, in the post-extubation and immediate pre-intubation period in intensive care, and to facilitate bronchoscopy.

Acute hypoxaemic respiratory failure

HFNOT is useful for the treatment of ARF due to its ability to provide an F_{IO_2} of close to 1.0, PEEP of ~5 cm H_2O, and humidified gases through a comfortable interface.

The FLORALI trial has shown that HFNOT can reduce intubation requirements in patients with non-cardiogenic ARF with a Pa_{O_2}/F_{IO_2} ratio of <200 mm Hg. No difference in intubation rate is seen in patients with a higher Pa_{O_2}/F_{IO_2} ratio. This trial also noted a significantly reduced mortality rate in patients receiving HFNOT, both during intensive care unit (ICU) admission and within 90 days.[9]

HFNOT can be particularly useful in ARF patients with increased work of breathing who do not tolerate facemask therapy or those who have a high secretion load. Much of the work done in this area has a focus on patient comfort and tolerability. A comparison of Venturi facemask oxygen therapy, HFNOT, and non-invasive facemask ventilation (NIV) in patients with ARF due to infection revealed the most improvement in subjective dyspnoea with HFNOT.[6] The greatest increase in arterial oxygen tension was seen with NIV, but this had the lowest patient acceptance score. Other studies corroborate these findings.[10]

HFNOT has also been used in patients with hypoxaemia due to cardiogenic pulmonary oedema, where the application of PEEP resulting from HFNOT led to improved dyspnoea and arterial oxygen tension.[3] Its use in chronic obstructive pulmonary disease (COPD) patients requires further evaluation, particularly in the

setting of acute exacerbations. It has been shown, however, that high-flow nasal cannulae oxygen therapy reduces respiratory rate and increases minute volume in COPD patients both at rest and during exercise.[11]

Patient selection is an important factor in the success of HFNOT therapy. As with NIV, delay in initiating invasive ventilation via tracheal intubation caused by inappropriate perseverance with HFNOT may result in increased ICU mortality and worsened outcomes.

Airway management

There is a place for HFNOT in emergency and elective airway management. Preoxygenation, to denitrogenate the lungs, provides an oxygen reservoir for use during apnoea. This is a core principle in airway management, not just in the anticipated difficult airway. Increasing the viable apnoeic window is highly desirable in the management of the difficult airway, and in those patients with a reduced functional residual capacity, or increased metabolic demand for oxygen. These patients will have a limited oxygen reservoir, and reduced time to desaturation. Obstetric, bariatric, and septic patients represent potential groups where preoxygenation with HFNOT may be beneficial. It has been used successfully in awake fibreoptic intubation, where a major advantage appears to be its ability to provide an $F_{I_{O_2}}$ of nearing 1.0 via soft nasal cannulae that allow the passage of a fibreoptic scope.[12]

Insufflation of oxygen into the lungs during apnoea can maintain oxygenation through diffusion. This effect is well described and is likely one of a number of mechanisms by which jet ventilation oxygenates the lungs. Recent attention has focused on the use of HFNOT in the difficult airway and its ability to increase the time to desaturation, and decrease the severity of the desaturation in anaesthetized patients, allowing for unhurried attempts at intubation.[13] This effect extends to the critical care population requiring intubation, where fewer and less severe episodes of arterial desaturation are seen when preoxygenated with HFNOT, rather than high-flow oxygen using a conventional facemask.[14] This effect is not seen in all populations, notably those with severe respiratory failure.[15]

Carbon dioxide (CO_2) is cleared to some extent in apnoeic application of HFNOT possibly due to diffusion after washout of CO_2 from the anatomical dead space. However, it is important to remember that periods of apnoea in excess of 15 min can be achieved with HFNOT, but arterial CO_2 levels may increase to dangerous levels, resulting in severe acidosis.

Extubation and postoperative use

Postoperative hypoxaemia is common in patients undergoing major abdominal surgery, due to derecruitment of lung alveoli, atelectasis, and altered respiratory mechanics secondary to pain. Increasing the $F_{I_{O_2}}$, although useful in treating the arterial hypoxaemia, will not treat the cause of the problem. The application of CPAP after elective abdominal surgery can reduce the need for tracheal intubation, and the development of postoperative chest infections in hypoxaemic patients.[16] The 'Optiflow for prevention of post-extubation hypoxemia after abdominal surgery' (OPERA) trial will assess postoperative hypoxaemia, pulmonary complications, and the need for NIV or tracheal intubation after abdominal surgery in patients receiving early HFNOT.[17] If this therapy is shown to reduce postoperative pulmonary complications then more widespread application of HFNOT, particularly in ward-based settings, may be beneficial.

The use of HFNOT has been assessed in the post-cardiac surgery population, where it was shown to reduce respiratory rate, and increase end-expiratory lung volume. It can reduce the requirement for CPAP via a facemask interface and re-intubation rates but has not been consistently shown to improve other respiratory parameters such as $S_{p_{O_2}}/F_{I_{O_2}}$ ratios or basal atelectasis.[18] There are some reports that a larger effect is seen in the obese population, but a recent study into this group of patients post-cardiac surgery failed to show any improvement in respiratory parameters between HFNOT and conventional oxygen therapy. Rates of re-intubation, however, were significantly reduced. It has been shown that HFNOT is not inferior in preventing re-intubation compared with NIV in this population.[19] This study compared 24 h of HFNOT with 6 h of therapy with bilevel positive airways pressure. A comparison with CPAP in the postoperative period would also be of use.

Other patient groups

There is a growing movement towards HFNOT use in patients undergoing bronchoscopy. It could be a useful tool in patients with mild hypoxaemia undergoing bronchoscopy. Patients undergoing bronchoscopy in a critical care setting are relatively hypoxaemic. Bronchoscopy increases V/Q mismatch, and may result in basal lung collapse due to suctioning of airways. Application of end-expiratory pressure during the procedure would be a logical counter to these effects, but choice of the appropriate method to achieve this should be patient-specific.

HFNOT is a comparatively well tolerated and comfortable method of respiratory support. In our centre like many other hospitals, it is used in selected ward environments. The support of a critical care outreach team is recommended to prevent unnoticed deterioration and the potential for delay in commencing mechanical ventilation if required. HFNOT could be suitable for use in some patients deemed not suitable for intubation, or patients requiring palliative care. It reduces respiratory rate in respiratory failure and can alleviate respiratory distress symptoms in cancer patients.[20] It has also been assessed as a long-term home therapy in COPD patients. It does not reduce frequency of exacerbations of COPD, but may reduce the duration of these events.[11]

Contraindications

Contraindications to the use of HFNOT are much the same as for NIV delivered via a facemask or hood. HFNOT should not delay mechanical ventilation in those with severe respiratory failure, particularly in type II respiratory failure. Any contraindication to the application of PEEP should prompt alternative methods of respiratory support to be sought. Additionally, it should not be used on those with reduced levels of consciousness, or uncooperative patients. In addition, epistaxis, facial injury, or airway obstruction should preclude its use.

Future applications

The applications for HFNOT are already extending beyond its use in critical care. In some centres, it is used hospital-wide and may become a replacement for conventional nasal cannula, allowing administration of warmed humidified oxygen to those not necessarily requiring high-flow gas. We anticipate that it may be of use in prehospital care and inter-hospital transfers, primarily for its ability to deliver an $F_{I_{O_2}}$ of close to 1.0.

Alongside the clinical advantages, HFNOT offers practical benefits such as improved patient compliance and the ability to

eat, drink, and communicate while receiving therapy. In our experience, these have a significant impact on patient morale. We anticipate growth in the use and acceptance of HFNOT and envisage that high flow, cold dry gases administered via a facemask may become a relic of the past.

The triad of humidity, compliance, and high F_{IO_2} that HFNOT offers is likely to be of use in a wide variety of clinical situations. There are various devices available for use, which deliver varying maximum flow rates and humidification. This is a rapidly evolving area and the evidence for its use in acute hypoxaemic respiratory failure, advanced airway management, and the post-operative population is growing.

Declaration of interest

None declared.

MCQs

The associated MCQs (to support CME/CPD activity) can be accessed at https://access.oxfordjournals.org by subscribers to *BJA Education*.

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