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The Role of High-Flow Nasal Oxygen Therapy (HFNOT) in Emergency Medicine: Efficacy and Clinical Applications

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ABSTRACT

Introduction: High-Flow Nasal Oxygen Therapy (HFNOT) is an increasingly utilized respiratory support modality in emergency medicine. It offers advantages over conventional oxygen therapy (COT) and non-invasive ventilation (NIV), including enhanced oxygenation, patient comfort, and physiological benefits. Despite growing interest, questions remain regarding its optimal use and effectiveness across different clinical scenarios.

Materials and methods: This review synthesizes current literature on the use of HFNOT in emergency departments, prehospital care, and patient transport. It explores underlying physiological mechanisms, device setup parameters, and clinical outcomes compared to conventional oxygen therapy (COT) and non-invasive ventilation (NIV), while also addressing limitations and implementation challenges.

Results: HFNOT improves oxygenation, reduces work of breathing, and enhances secretion clearance through mechanisms such as dead space washout and mild positive airway pressure. It is well-tolerated and shows promise in managing acute respiratory failure. However, evidence is limited for certain populations, such as those with blunt chest trauma. HFNOT may delay intubation in some cases and requires proper training for safe implementation.

Conclusions: HFNOT is a valuable, less invasive respiratory support strategy in emergency medicine. Its use is expected to expand with accumulating evidence and increased provider experience. Further research is needed to define its role in non-critical care settings and specific high-risk groups.

Keywords: High-flow nasal oxygen therapy (HFNOT); acute respiratory failure; emergency medicine; non-invasive ventilation (NIV); hypoxemia; prehospital care.

Introduction

Oxygen therapy is a crucial treatment in emergency medicine, necessary for maintaining aerobic metabolism in patients with severe conditions. It is commonly used in both intensive care and emergency environments, delivered through methods such as nasal cannulas, face masks, high-flow systems, or mechanical ventilation. By ensuring adequate oxygen supply, it helps stabilize patients and support function of vital organs during acute medical emergencies [1].

Oxygen is one of the oldest drugs available to mankind. However, it is also one of the most inappropriately administered drugs [2]. Oxygen therapy, while essential for managing hypoxemia, can also lead to side effects and adverse outcomes. Excessive or liberal administration of oxygen can result in oxygen toxicity. High concentrations of oxygen promote the production of free radicals, which cause cellular damage, potentially leading to apoptosis or necrosis, especially in the presence of other factors such as infection. The cell death triggered by these processes releases mediators that, in combination with the free radicals, cause further cellular damage, creating a harmful cycle [3]. Additionally, the delivery of dry, cold oxygen can lead to the drying of secretions and damage to the airway mucosa, contributing to patient discomfort and further increasing the risk of airway collapse [2]. This highlights the importance of implementing a conservative, normoxic oxygenation strategy to minimize the harmful effects while ensuring adequate oxygenation [3].

This review explores the role of High-Flow Nasal Oxygen Therapy (HFNOT) in emergency medicine, analyzing its mechanisms of action, clinical efficacy, and practical applications. By reviewing current literature and clinical data, it aims to assess whether HFNOT provides a superior alternative to traditional oxygen therapies and its place within the evolving field of acute respiratory care.

High-Flow Nasal Cannula (HFNC)

Setup and Application

The high-flow nasal cannula (HFNC) is a device used for managing acute respiratory failure (ARF) noninvasively, typically in the early stages, and is often used in combination with conventional oxygen therapy (COT) and non-invasive ventilation (NIV) [4].

HFNC is widely used in different healthcare environments for the management of both acute and chronic respiratory failure [5]. HFNC is mainly used in critical care settings but can also be set up in medium- to high-dependency wards and at home. The system consists of four key components: a flow generator (e.g., air/oxygen blender or turbine), a heated humidifier, heated tubing with a chamber kit, and a nasal cannula interface, which comes in various sizes to fit different facial anatomies. In hospitals, the device requires both an oxygen and a high-pressure air source, while turbine-based devices are adapted for home use. Parameters like flow rate, FiO_2, and temperature can be adjusted to optimize patient comfort, with limits depending on the device. Flow rates are typically titrated to 60-70 L/min to match the patient's inspiratory needs, preventing the inhalation of ambient air and maintaining stable FiO_2 levels [7,8]. For patients with acute respiratory distress, higher flow rates up to 100 L/min or more may be required, and the maximum achievable flow rate should be used based on the device [7]. FiO_2 can be modified within the range of 60% to 100% via the oxygen inlet. Integrated oxygen sensors monitor the FiO_2 of the inspired gas, helping to reduce any differences between the set value and the actual FiO_2 delivered to the patient [6]. Most manufacturers suggest adjusting the temperature to approximately 37°C to maintain a relative humidity of 100% [15]. Devices usually allow temperature settings ranging from 31°C to 39°C, with the option to set a temperature lower than the patient's core body temperature based on individual preferences [7]. HFNC is also a valuable support tool, allowing patients to eat, drink, and communicate while taking breaks from positive airway pressure, which is commonly used to treat various causes of respiratory failure in different hospital environments [7].

Physiological Impact of HFNC

HFNC offers several advantages, including improved patient comfort and physiological benefits such as enhanced oxygenation, alveolar recruitment, humidification and heating, increased secretion clearance, and reduction of dead space [4].

Anatomical dead space refers to parts of the respiratory tract where air reaches the alveoli but does not engage in gas exchange (O_2 and CO_2). In normal ventilation, around 30% of tidal volume (TV) is ineffective due to dead space. In COPD, increased dead space exacerbates ventilation impairment. The application of high-flow gas has been shown to enhance ventilation by reducing the impact of dead space.[9] HFNC is administered through nasal cannulae, forming an oxygen reservoir by continuously flushing exhaled gases from the upper airways [10]. As the flow rate increases, dead space washout is enhanced, leading to improved gas exchange and a reduction in $PaCO_2$ [7],[11].

The HFNC device is an open system, and the high flows it generates are sufficient to overcome the expiratory flow, creating a small positive pressure in the airways, known as positive end-expiratory pressure (PEEP), generally around 3 cmH_2O [11,28]. PEEP helps recruit alveoli (increasing the number of alveoli involved in ventilation) and promotes the movement of lung fluid from the alveoli to the perivascular interstitial space, as seen in conditions like pulmonary oedema [11]. However, the level of positive end-expiratory pressure is typically low, variable, and difficult to control precisely [30].

HFNC improves both the work of breathing and pulmonary mechanics. The work of breathing refers to the energy expended to achieve a constant tidal volume (TV) over time, and it is influenced by lung compliance and airway resistance. Clinically, increased work of breathing is indicated by symptoms such as nasal flaring and the use of abdominal muscles. In cases of respiratory distress, HFNC helps to reduce the respiratory rate [12]. HFNC also improves thoracoabdominal synchrony compared to conventional oxygen therapy in patients with mild to moderate respiratory distress [13].

HFNC enhances mucociliary clearance. The respiratory epithelium is highly sensitive to changes in airway temperature and pressure, performing optimally at core body temperature and 100% relative humidity [7]. A decrease in temperature can change the consistency of respiratory secretions and impair ciliary function, thereby slowing mucociliary clearance [15]. The delivery of conventional oxygen therapy, a cool, dry gas, modifies the physical and biochemical characteristics of respiratory mucus and can trigger bronchoconstriction. This effect is more pronounced in patients with pre-existing airway conditions, such as COPD. Impaired mucociliary clearance increases the risk of mucus plugging, exacerbates infections, and leads to a decline in lung function [15]. Effective clearance of tracheobronchial secretions happens when inhaled air is fully saturated and conditioned to 37°C in patients with obstructive airway diseases [14]. Therefore, the heated humidification in HFNC circuits improves patient comfort and adherence by helping mucociliary clearance and keeping moisture levels in the airways at a comfortable level [15].

These benefits can help prevent worsening lung function and reduce the need for endotracheal intubation [4].

ROX index

The ROX index, which compares a patient's oxygen saturation (SpO_2) to the fraction of inspired oxygen (FiO_2) and respiratory rate, is a clinical tool used to regularly evaluate whether oxygen therapy should be intensified or if timely intubation is necessary in cases of hypoxemic respiratory failure [15]. The benefit of the ROX index lies in its ability to combine key indicators of a patient's respiratory condition into a single value [15].

The authors recommended continuing the current treatment when the ROX index exceeds 4.88 at all three time intervals. However, if the ROX index falls below 2.85, 3.47, and 3.85 at 2, 6, and 12 hours after starting HFNC therapy, endotracheal intubation should be considered. For intermediate ROX index values at each time point, HFNC support should be adjusted upward, followed by reassessment in 30 minutes. Additionally, they found that patients who eventually required endotracheal intubation experienced smaller increases in their ROX index between 2 and 12 hours, as well as between 6 and 12 hours [15].

Comparison High-Flow Nasal Therapy with Non-Invasive Ventilation and Conventional Oxygen Therapy

For the past two decades, non-invasive ventilation (NIV) has been the primary approach for treating patients with hypercapnia by providing positive pressure ventilation [16]. NIV is frequently employed as an alternative approach for respiratory support, helping to minimize the necessity for invasive ventilation in various medical conditions [18].

Unfortunately, NIV is not suitable for some patients who poorly tolerate a tight-fitting mask. Additionally, it is associated with a relatively high risk of adverse effects, including claustrophobia, nasofacial skin damage, eye irritation, as well as gastric and intestinal distension, which in some cases may result in aspiration - a severe complication with a poor prognosis [16]. Multiple studies have shown that patients generally find high-flow nasal oxygen more comfortable and easier to tolerate compared to non-invasive ventilation [31]. Moreover, NIV is not advised for patients with hypercapnia but without acidosis, as it does not show superior outcomes compared to conventional oxygen therapy (COT) in reducing intubation rates or mortality. In such cases, other options, such as conventional oxygen therapy (COT) and high-flow nasal cannula (HFNC), may be considered for certain patients to avoid unnecessary invasive ventilation. A retrospective cohort study showed that HFNC was not associated with a statistically significant reduction in intubation rates. However, it was associated with a lower mortality risk and a greater number of ventilator-free days at day 28, compared to non-invasive ventilation (NIV) in patients with suspected sepsis and acute respiratory distress [18].

Nevertheless, there is currently no established alternative for patients with hypercapnia who are not suitable for NIV [16].

Conventional oxygen therapy can be delivered through nasal cannulas at flow rates of up to 5–6 L/min, simple face masks at approximately 10 L/min, and non-rebreather masks at 15–20 L/min. However, in cases of hypoxemic respiratory failure, where patients may require flow rates as high as 60 L/min, traditional oxygen delivery methods often fail to provide adequate support for patients' respiratory needs [7]. Compared to conventional oxygen therapy (COT) administered through a standard nasal cannula or face mask, high-flow nasal oxygen therapy (HFNOT) offers more accurate and stable oxygen delivery, particularly in terms of maintaining a consistent fraction of inspired oxygen (FiO_2), which is difficult to achieve with COT lacking oxygen blenders [17].

However, standard nasal cannula and face mask are insufficient for patients with severe hypoxemia, often resulting in treatment failure [19]. Beyond its superior oxygen delivery, HFNO also enhances the breathing pattern, promotes airway secretion clearance, and improves patient comfort. Additionally, it facilitates the washout of upper airway dead space and may generate positive end-expiratory pressure (PEEP), both of which help reduce the work of breathing and enhance oxygenation [17].

Limitations of High-Flow Nasal Therapy

One of the challenges associated with initiating HFNC is the potential for early discomfort. However, this can usually be managed by slowly titrating the flow rate to the target level, allowing patients to adapt more easily [7]. Skin irritation may occur as a side effect of HFNC therapy, although it tends to be less severe compared to the complications often associated with non-invasive ventilation (NIV) [15]. In comparison to conventional oxygen therapy, high-flow nasal cannula treatment involves higher costs [20]. In addition, it is an intervention with its own intricacies that require additional training for the multidisciplinary team in the ward and critical care settings to initiate HFNC therapy. Furthermore, HFNC may delay intubation and may also delay time-critical discussions regarding the limits of care, treatment, resuscitation, and making end-of-life decisions [15].

HFNC is contraindicated in patients with altered levels of consciousness, including severe agitation, airway obstruction, risk of aspiration, facial injuries (especially nasopharyngeal trauma or recent surgery), respiratory arrest, hemodynamic instability, excessive sputum production, or claustrophobia [15].

Application of High-Flow Nasal Therapy (HFNT) in Emergency Medicine

High-flow nasal therapy (HFNT) has demonstrated both established and developing clinical applications across various healthcare settings, including the emergency department

(ED), offering significant physiological benefits in managing patients with acute respiratory conditions [15].

Acute Hypoxemic Respiratory Failure

In the management of acute hypoxemic respiratory failure (AHRF), careful monitoring of patients on HFNC therapy is crucial to ensure timely intubation when necessary [6]. Patients with acute hypoxemic respiratory failure (AHRF) who are not intubated often show abnormalities in gas exchange and respiratory mechanics [27]. While HFNC is not commonly applied in standard clinical practice for cardiogenic pulmonary edema, it may offer therapeutic benefits. Current guidelines recommend the application of positive airway pressure to enhance oxygen levels and reduce cardiac afterload [15]. Research indicates that HFNC can provide similar physiological benefits while offering greater comfort to patients, and it may help reduce the intensity of dyspnea within the first hour of therapy [15]. A randomized controlled trial involving 128 patients with acute cardiogenic pulmonary edema (ACPE) demonstrated that high-flow nasal oxygen (HFNO) significantly reduced respiratory rate compared to conventional oxygen therapy (COT) after one hour of treatment [29]. Nonetheless, findings have not shown significant differences in admission rates, lengths of stay in the emergency department or hospital, nor in the need for NIV or intubation [15]. Additional randomized controlled trials (RCTs) focused on patients with cardiogenic pulmonary edema causing hypoxemic respiratory failure are necessary before HFNC can be formally included in the management guidelines for this condition [15].

Acute Hypercapnic Respiratory Failure

Acute hypercapnic respiratory failure (AHRF) occurs when there is an accumulation of carbon dioxide (CO_2) in the blood due to inadequate ventilation. It is commonly seen in patients with severe chronic obstructive pulmonary disease (COPD) during acute exacerbations. High-flow nasal cannula (HFNC) therapy has shown promise in managing AHRF by improving ventilation and oxygenation. Although initial studies focus primarily on critical care settings, there is potential for HFNC to be used at home for patients with severe COPD and frequent exacerbations [32]. HFNC is effective in treating acute exacerbations of chronic obstructive pulmonary disease (AECOPD) by enhancing the washout of dead space, which improves gas exchange and reduces PaCO2 levels [15]. The 2019 systematic review by Pisani et al. reported that HFNC can maintain stable PaCO2 levels, although oxygenation tends to decline slightly in comparison to NIV. Additionally, HFNC was found to reduce the work of breathing to a degree similar to that of NIV [21]. HFNC is also considered to provide greater comfort than both conventional oxygen therapy and NIV [21]. Further research, such as randomized controlled trials, is needed to assess whether HFNC therapy can be a safe, effective, and cost-efficient solution for managing AHRF outside of hospital settings, potentially reducing hospital admissions and improving patient quality of life [32].

Application of HFNC in Emergency Transport and Prehospital Care

High-flow nasal cannula (HFNC), due to its multiple benefits compared to standard oxygen therapy and both non-invasive and invasive ventilation, is regarded as an effective and appropriate oxygenation method for use in prehospital care and during patient transfers [15]. Al-Mukhaini and Al-Rahbi found that HFNC can be safely used in non-critical care pediatric environments, as long as there is adequate expert supervision and monitoring [22]. Reimer et al. demonstrated that HFNC was effective not only in pediatric patients but also in adults, with no signs of physiological deterioration after patient transfer [23]. Inkrott and White suggested that HFNC is likely to become a standard treatment in air transport due to its ease of setup and comparable outcomes to NIV in reducing the need for intubation. They emphasized the importance of including HFNC in air transport programs, with proper planning for equipment and logistics before patient transfer [24].

Effectiveness of High-Flow Nasal Cannula in Assisting Tracheal Intubation in the Emergency Department

The use of HFNC during tracheal intubation was potentially linked to higher minimum SpO2 levels compared to conventional oxygen therapy in non-trauma patients in the emergency department. This indicates that HFNC may improve safety during intubation in the ED.[25]

High-Flow Nasal Cannula Therapy in Managing Hypoxemia in Blunt Chest Trauma Patients

A study examining High-Flow Nasal Cannula (HFNC) in patients with blunt chest trauma found that early HFNC application, when combined with non-invasive ventilation (NIV), did not significantly reduce the need for mechanical ventilation or respiratory complications compared to conventional oxygen therapy (COT). While HFNC may offer some potential benefits in this context, the study concluded that there is insufficient evidence to support its routine use for preventing respiratory failure in high-risk chest trauma patients. Further research is needed to more thoroughly assess the effectiveness of HFNC in this specific patient group [26].

Future Perspectives and Challenges in the Use of High-Flow Nasal Cannula

Most HFNC studies have been conducted in critical care settings. However, more research is needed to assess its feasibility and effectiveness in medical wards, where nurse-to-patient ratios are much lower. HFNC could provide a simpler form of respiratory support, as it is easy to use and requires fewer interventions for airway management. As healthcare professionals become more familiar with HFNC and receive proper training, its use in clinical practice is expected to improve over time [15].

Conclusions

High-Flow Nasal Oxygen Therapy (HFNOT) has proven to be a valuable intervention in emergency medicine, providing enhanced oxygenation, improved patient comfort, and physiological benefits, such as better alveolar recruitment, enhanced secretion clearance, and reduced work of breathing. HFNC stands out as an effective alternative to conventional oxygen therapies and non-invasive ventilation (NIV) in the management of acute respiratory failure, particularly in patients with hypoxemic and hypercapnic conditions.

While HFNC shows significant promise in critical care settings and for prehospital transport, it also presents challenges, including cost, the need for specialized training, and contraindications for certain patient populations. Further research is necessary to evaluate its use in non-critical care settings and its potential to prevent respiratory failure in high-risk conditions such as blunt chest trauma.

In summary, HFNC proves to be a valuable tool in emergency medicine, providing a less invasive method for respiratory support. Its clinical use is expected to increase as further high-quality evidence becomes available and healthcare providers become more skilled in its application.

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