Clinical Critical Care

สมาคมเวชบำบัดวิกฤตแห่งประเทศไทย
THE THAI SOCIETY OF CRITICAL CARE MEDICINE

E-ISSN 2774-0048

VOLUME 32 NUMBER 1
JANUARY-DECEMBER 2024

Clinical Critical Care
Volume 32, Article ID e240010, 10 pages
https://doi.org/10.54205/ccc.v32.267396
REVIEW
eISSN 2774-0048

Perioperative use of high flow nasal cannula

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OPEN ACCESS
Citation:
Visuthisakchai S, Kongsayreepong S. Perioperative use of high flow nasal cannula. Clin Crit Care 2024; 32: e240010.

Received: January 19, 2024
Revised: April 23, 2024
Accepted: May 13, 2024

Data Availability Statement:
The data and code were available upon reasonable request (Suneerat Kongsayreepopng, email address: suneeratkong@gmail.com)

Funding:
The authors have stated that they have no source of support and fundings.

Competing interests:
The authors have stated that they have no potential conflict of interest relevant to this article.

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ABSTRACT:

High flow nasal cannula (HFNC) is an innovative oxygen therapy system that has gained increasing popularity in recent decades, particularly in the field of critical care medicine. The device provides a more constant and higher FiO_2, generates low levels of PEEP, reduces dead space ventilation, and conditions the inspired gas, which collectively results in a reduction in work of breathing (WOB) and improved patient comfort. While the application of HFNC in critically ill patients is well-established and supported by a large body of evidence, studies of HFNC during the perioperative period are limited. However, the working mechanisms of HFNC align with physiological demands across various anesthetic processes. Consequently, this system could potentially serve as an alternative oxygen delivery system for surgical patients during perioperative care. In this article, we summarize the working principles and the effects provided by HFNC, review its implementation during the perioperative period, and discuss the current evidence regarding its use.

Keywords: High flow nasal cannula; Perioperative period; Preoxygenation; Apneic oxygenation; Post-extubation

INTRODUCTION

High flow nasal cannula (HFNC) is an advanced noninvasive respiratory support that delivers heated and humidified high flow gas (flow > 30 liters per minute (LPM)) to the patient. The system consists of several important components, including an air-oxygen blender, an active humidifier, a single-limb heated inspiratory circuit, and a specially designed nasal cannula. With each part working together, this device is capable of delivering a flow rate of up to 60 LPM with an adjustable fraction of inspired oxygen (FiO_2) ranging from 21% to 100% [1,2]. Since its first introduction into clinical practice in the early 2000s as an alternative treatment to CPAP for management of apnea of prematurity in preterm infants, the device has gained popularity and expanded its usage among neonates, children, and adults [2-4].

Over the course of the last few decades, the physiological effects of HFNC have been thoroughly investigated, resulting in a better understanding of its potential role as a non-invasive respiratory support device. Along with this evidence, recent meta-analyses and clinical practice guidelines have encouraged the use of HFNC in several conditions involving acute hypoxic respiratory failure and during the post-extubation period, which are mostly encountered in critically ill patients [5-7]. However, due to its fascinating results both physiologically and clinically, the application of this novel oxygen delivery system has also been extended to cover respiratory care during the perioperative period and anesthetic care.

In this article, we provide a concise review of the physiological effects and clinical benefits of HFNC, as well as its implementation during the perioperative period.

PHYSIOLOGICAL EFFECTS AND CLINICAL BENEFITS OF HFNC

HFNC provides its advantages to the respiratory system through various physiological mechanisms.

1. Delivery of higher and more constant FiO_2

Usually, tidal volume and inspiratory flow are not consistent and fluctuate from one breath to the next, depending on the patient's status. Consequently, when oxygen therapy is administered, the difference between inspiratory flow and delivered oxygen flow inconsistently changes, resulting in an unstable FiO_2 [2,4,8]. In cases of acute respiratory failure (ARF), patients often require higher inspiratory flow rates, typically ranging from 30-40 LPM, but this demand can occasionally exceed 120 LPM [1,8]. However, low flow oxygen devices can only provide a maximum oxygen flow of up to 15 LPM [8]. In this situation, the patient's required inspiratory flow exceeds the flow provided by traditional oxygen therapy. As a consequence, the patient will draw in additional flow from the surrounding environment, resulting in a significantly lower FiO_2 than the delivered gas. Conversely, HFNC can generate higher flow rates of up to 60 LPM, which match or even exceed the patient's inspiratory flow demand. This, in turn, leads to a reduction in the mixing of room air and the consequent dilution of administered oxygen, causing a more constant FiO_2 [2,4,8,9].

2. Positive end expiratory pressure effect

In spite of the fact that HFNC operates as an open system, it can produce positive end expiratory pressure (PEEP). Two potential explanations account for this phenomenon. To begin with, the elevated gas flow rate pressurizes the patient's upper airway, a fact confirmed by the measurement of nasopharyngeal pressure. In addition, the patient's exhalation against the continuous high flow of incoming gas imposes an expiratory resistance, which substantially results in PEEP. For these reasons, the PEEP effect of the device proportionally correlates with the prescribed flow rate, and breathing with an open mouth causes the gas to escape from the system, thereby reducing this effect [1,2,4,8,9].

Multiple physiologic studies have demonstrated that HFNC could create a low-level positive airway pressure in the nasopharynx. Parke, et al. [10], through the measurement of nasopharyngeal pressure, discovered that HFNC produced higher positive airway pressure in comparison to oxygen face masks. Despite the positive airway pressure showing a linear correlation with the gas flow rate, they noted that the pressure remained relatively low, generally around 3 cmH_2O [1,4,9-13]. Nonetheless, it remains challenging to demonstrate whether this minimal positive nasopharyngeal pressure results in PEEP, primarily due to the inability to directly measure alveolar pressure. Fortunately, advancements in electrical impedance tomography (EIT) technology have enabled the evaluation of lung volume by monitoring alterations in lung impedance [1].

KEY MESSAGES:

- HFNC is an oxygen delivery system that provides heated and humidified high flow gas, offering several physiological advantages to the respiratory system.
- The application of HFNC is extensively validated in critically ill patients, and current clinical practice guidelines recommend the use of the device in various clinical contexts, including acute hypoxemic respiratory failure and the post-extubation period.
- Given the advantageous effects of the device, HFNC has been applied in various perioperative settings, including induction of anesthesia, airway and endoscopic procedures, and postoperative care.

In their investigations involving healthy individuals and post-cardiac surgery patients, Reira, et al. [14] and Corley, et al. [15] explored the impact of HFNC on changes in lung volume using EIT. Their research revealed that HFNC led to an augmentation of end-expiratory lung impedance (EELI), indicating an increase in end-expiratory lung volume (EELV). A separate study by Mauri, et al. [16] also supported these findings in patients with acute hypoxemic respiratory failure. Therefore, it is reasonable to infer that the utilization of HFNC results in the generation of sufficient PEEP, consequently leading to an increase in EELV [1].

3. Decreased dead space ventilation

Due to HFNC's capacity to provide higher gas flow rates that match or even surpass the patient's flow requirement, it facilitates the removal of carbon dioxide (CO_2) from the airway and replaces it with oxygen-enriched gas. This, in turn, reduces the anatomical dead space, reduces CO_2 levels, and enhances alveolar ventilation [1,2,4,9]. Moller, et al. [17,18] verified this hypothesis through experimental studies conducted in simulated airway models and with healthy volunteers. They additionally observed that the efficiency of this flushing effect depends on the gas flow rate.

4. Heating and humidifying the gas

The condition of the inspired gas, including temperature and humidity, has notable impacts on both respiratory mechanics and mucosal function. A physiological experiment carried out by Fontanari, et al. [19] on twelve healthy subjects demonstrated a significant increase in inspiratory resistance when the volunteers inhaled dry and cold air through nasal breathing. Moreover, it is essential to maintain the appropriate levels of gas moisture and temperature to optimize mucociliary function and facilitate the effective clearance of secretions [1,20,21]. HFNC, with its active heated humidifier, preconditions the inspired gas, thereby offering these advantages to patients [1,2,22].

By integrating these diverse physiological mechanisms, HFNC enhances several aspects of the patient's respiratory system. This includes improved gas exchange, increased lung volume, enhanced dynamic lung compliance, and a more consistent distribution of ventilation. Consequently, patients experience a reduced work of breathing, less dyspnea, and greater overall comfort in their breathing [1,2,23]. The physiological effects and impacts of HFNC on patient's respiratory systems are summarized in Figure 1.

HFNC DURING PERIOPERATIVE MANAGEMENT

Airway management is a critical procedure during perioperative care, especially in the context of general anesthesia. The primary objective of perioperative respiratory support is to ensure adequate oxygenation, thereby reducing the incidence of both respiratory and non-respiratory complications. To achieve this goal, anesthesiologists require not only airway management expertise but also effective oxygen therapy equipment. HFNC, which offers the potential benefits discussed earlier, is becoming more popular and seeing increased use in various areas of anesthesiology [24,25]. Figure 2 provides an overview of the recent applications of HFNC in anesthetic management.

INDUCTION OF ANESTHESIA

The induction of anesthesia refers to the process of transitioning a patient from a state of wakefulness to unconsciousness, typically achieved through the administration of anesthetic and neuromuscular blocking agents [26,27]. Consequently, after a patient is anesthetized, the risk of hypoxemia becomes more evident, and oxygen supplementation is mandatory. The oxygenation procedure during the induction of anesthesia can be divided into two phases based on the timing of their implementation: preoxygenation and peroxygenation [25].

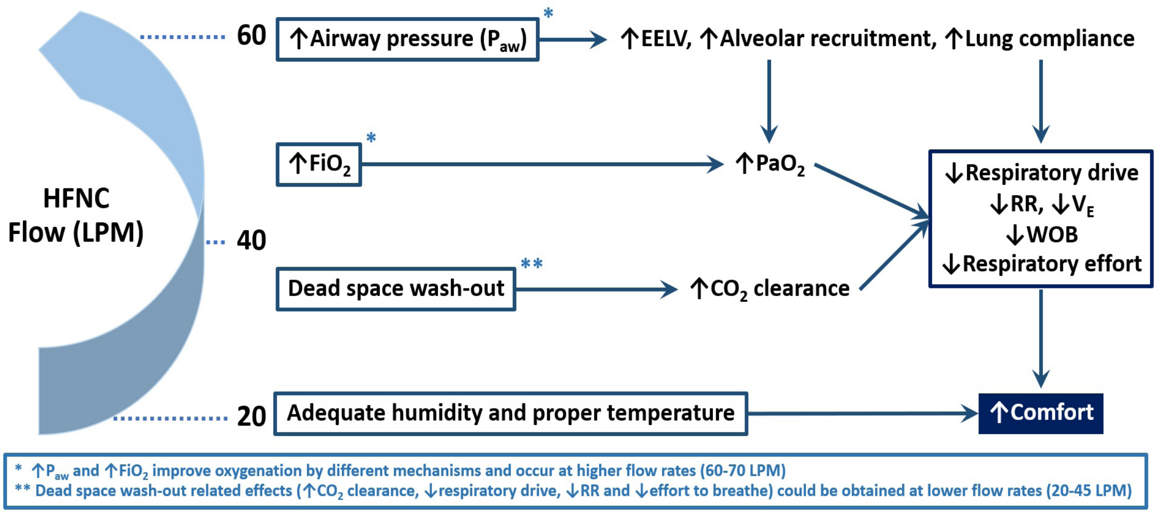

Figure 1. Schematic presentation of the physiological effects of HFNC and possible impact on respiratory system. HFNC high flow nasal cannula, Paw airway pressure, FiO_2 fraction of inspired oxygen, EELV end-expiratory lung volume, RR respiratory rate, VE minute ventilation, WOB work of breathing. (Adapted from "Use of nasal high flow oxygen during acute respiratory failure," by JD. Ricard, et al., 2020, Intensive care medicine, 46(12), p. 2239.) [23]

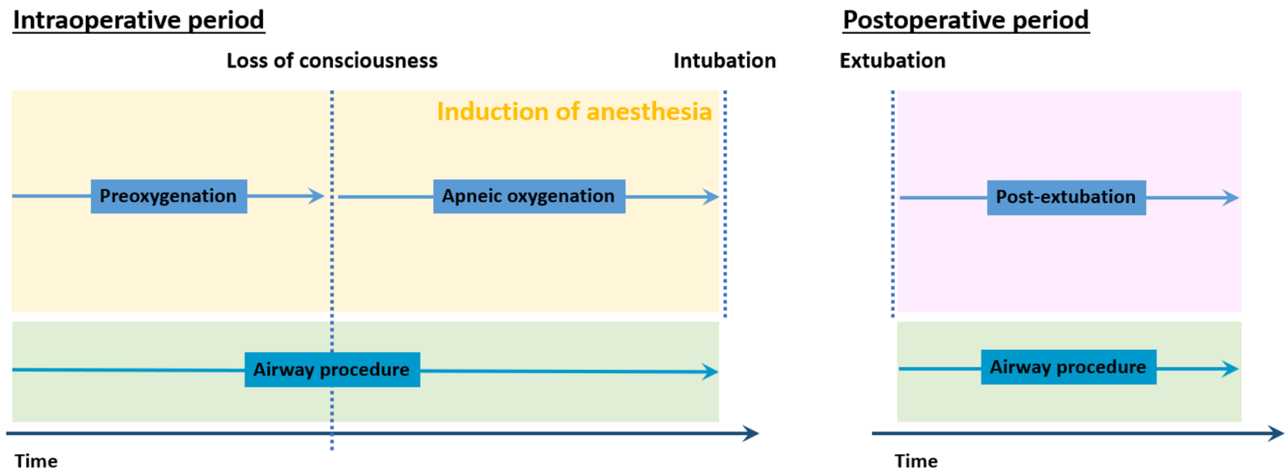

Figure 2. Recent applications of HFNC during anesthetic management. (Adapted from "High-flow nasal oxygenation for anesthetic management," by HJ. Kim and T. Asai, 2019, Korean journal of anesthesiology, 72(6), p. 527-547.) [25]

PREOXYGENATION

Preoxygenation is the process of augmenting the body's oxygen reserves by administering oxygen prior to the induction of anesthesia. Its primary objectives are to prolong the safe apnea time (a period of apnea without hypoxemia) after the induction process and to provide additional time for the anesthesiologist to secure the airway, especially in challenging situations [24,25,28]. This practice is now considered a standard of care and has been emphasized in various clinical practice guidelines and by international healthcare organizations [24].

The physiological basis of preoxygenation involves the denitrogenation of the lungs. Breathing with high FiO_2 leads to the replacement of nitrogen in the lung's functional residual capacity (FRC), thus significantly increasing oxygen storage [24,28]. Further expanding the size of this oxygen reservoir can be more effectively accomplished by reducing the extent of dependent atelectasis [24]. The conventional method of preoxygenation consists of providing 100% oxygen through a properly sealed face mask, with the aim of achieving adequate preoxygenation, as indicated by an end-tidal oxygen partial pressure (EtO_2) exceeding 90% [24,25].

With the ability to consistently supply higher FiO_2 levels and a sufficient PEEP effect to increase EELV, HFNC is considered an appealing option for preoxygenation [25]. Ang, et al. [29] performed a prospective observational study with 20 healthy volunteers who breathed through HFNC with a flow rate of 70 LPM while keeping their mouths closed. The study revealed that HFNC increased the EtO_2 from an initial range of 14-17% to 78-92% after 3 minutes of application. However, it's worth noting that in half of the volunteers, the EtO_2 did not reach the desired threshold of 90%. In another observational study conducted by Pillai, et al. [30], involving 10 adult volunteers, HFNC with a flow rate of 60 LPM was compared to a face mask with an oxygen flow of 10 LPM for 3 minutes. Their findings showed that only when using HFNC with the mouth closed, the mean EtO_2 was similar between the two techniques. Two randomized controlled studies from different groups of investigators also compared the efficacy of the transnasal humidified rapid-insufflation ventilatory exchange (THRIVE) technique, a form of high flow nasal oxygen therapy (flow rate up to 70 LPM, FiO_2 100%), to a face mask as a preoxygenation method (flow rate 10-12 LPM, FiO_2 100%) in patients undergoing rapid sequence induction (RSI) of anesthesia for emergency surgery [31,32]. In both of these studies, there were no significant differences in oxygenation indices, either PaO_2 or SpO_2, between the two comparison groups. Lastly, the most recent systemic review and meta-analysis, published in 2022, by Li and Yang [33], which included five randomized controlled trials (RCTs), revealed that THRIVE has an advantage in providing higher PaO_2 after preoxygenation but no differences in $PaCO_2$, apnea time, or SpO_2 after successful intubation.

Preoxygenation using HFNC, however, may not deliver as promising results in certain patient populations, such as pregnant women, obese individuals, patients with established acute respiratory failure (ARF), and those undergoing neurosurgical procedures.

Preoxygenation with HFNC in pregnancy

Pregnant women are at an increased risk for hypoxemia and difficult intubation due to several pregnancy-related changes, such as airway edema, reduced respiratory reserves (decreased FRC), increased oxygen consumption, and a higher risk of aspiration. Evidence from both observational and randomized controlled studies indicated that only approximately 50% of patients using HFNC were able to reach the target EtO_2 threshold of 90% [34,35]. Furthermore, when compared with standard face mask oxygenation, HFNC yielded significantly lower estimated marginal mean EtO_2 levels (87.4%, 95% CI 85.5 to 89.2 versus 91.0%, 95%CI 89.3 to 92.7, p=0.02) [35]. The phenomenon can be attributed to several factors, including some subjects breathing with their mouth open while using HFNC, leading to a dilution of administered oxygen. Additionally, anatomical and physiological alterations in the upper airway of a pregnant woman, including congested nasal mucosa and edema of the airway structure, may alter the aerodynamic effects of the device by reducing the level of positive airway pressure, potentially contributing to reduced EtO_2 levels during HFNC use [24,34,35].

Preoxygenation with HFNC in obese adults

The physiological alterations associated with obesity have an impact on multiple aspects of the respiratory system. These changes are related to body habits, such as the development of basal lung atelectasis, a reduction in FRC, an increase in closing volume, elevated oxygen consumption, and difficulties in airway management. As a result, patients with obesity are more susceptible to respiratory related complications [24,25]. In a RCT involving morbidly obese patients (BMI ≥ 35 kg/m^2) undergoing bariatric surgery, three preoxygenation techniques, namely face mask oxygenation (standard group), HFNC, and continuous positive airway pressure (CPAP) at 7 cmH_2O, were compared. It is noteworthy that preoxygenation using HFNC resulted in significantly increased PaO_2 levels in comparison to the standard group, and these levels were comparable to those observed with the CPAP group [36]. However, in the PREOPTIPOP trial [37], a RCT involving obese patients (BMI ≥ 35 kg/m^2) scheduled for surgery, when HFNC was compared to NIV, the median EtO_2 within 2 minutes after successful intubation was significantly higher in the NIV group (88% [IQR 82-90] versus 76% [IQR 66-82], mean difference 11.4% [95%CI 7.7 to 15.1]; p<0.001). HFNC, in contrast, resulted in lower EtO_2, lower SpO_2, and more oxygen desaturation than NIV. Based on this available evidence, HFNC can serve as an acceptable alternative device for preoxygenation in obese patients when NIV is either unavailable or contraindicated [24].

Preoxygenation with HFNC in patients with ARF

Clinical data regarding the use of HFNC for preoxygenation in surgical patients with established ARF is limited. However, valuable insights are summarized from studies involving critically ill patients [24]. In a multicenter RCT, the PREOXYFLOW trial [38], conducted by French investigators, compared preoxygenation with HFNC to a high fraction-inspired oxygen facial mask (HFFM) in ICU patients with acute hypoxemic respiratory failure, requiring endotracheal tube intubation (ETI). In both groups, pneumonia was the leading cause of respiratory failure, accounting for 40.3% in the HFNC arm and 50.9% in the HFFM arm. Notably, a higher percentage of patients in the HFNC group experienced extrapulmonary ARDS (30.6% compared to 19.3%). The two groups exhibited similarity in terms of the SAP II scores (mean [SD]; HFNC 54.5 [20.2] versus HFFM 51.3 [16.5]) and the initial PF ratios (mean [SD]; HFNC 120.2 mmHg [55.7] versus HFFM 115.7 mmHg [63]). The lowest SpO_2 during ETI was not statistically different between the two groups (median [IQR]; HFNC 91.5% [80-96] versus HFFM 89.5% [81-95], p=0.44). Similarly, SpO_2 at the end of preoxygenation was also comparable in both groups (mean [SD]; HFNC 97.1% [3.8] versus HFFM 96.3 [4.4], p=0.98).

In the FLORALI-2 study [39], another multicenter RCT, HFNC, was directly compared with NIV as a preoxygenation method in adult patients undergoing tracheal intubation for acute hypoxemic respiratory failure. The baseline characteristics of the participants demonstrated no significant differences, including SAP II scores (mean [SD]; HFNC 51 [19] versus NIV 52 [20], p=0.85) and SOFA scores (mean [SD]; HFNC 6 [3] versus NIV 5 [3], p=0.31). Respiratory infections were the predominant cause of ICU admissions, accounting for 35% in both intervention groups. Additionally, there were no statistical differences in PF ratios at enrollment (mean [SD]; HFNC 148 mmHg [70] versus NIV 142 [65], p=0.40). Severe hypoxemia, defined as $SpO_2 < 80\%$, was equally observed in both groups, with 27% occurring after preoxygenation with HFNC and 23% with NIV (absolute difference -4.2%, 95% CI -13.7 to 5.5, p=0.39). However, within the subgroup of patients with a baseline moderate to severe hypoxemia (PF ratio < 200 mmHg), a higher percentage of those using HFNC experienced severe hypoxemia compared to individuals receiving NIV, with 35% in the HFNC group and 24% in the NIV group (adjusted odds ratio 0.56, 95% CI 0.32 to 0.99, p=0.0459).

A network meta-analysis examined various preoxygenation techniques used before intubation in patients suffering from ARF, allowing for a comprehensive comparison between individual methods. The study indicated that employing NIV for preoxygenation notably resulted in significantly lower desaturation, as measured by the lowest SpO_2 during intubation, in comparison to both conventional oxygen therapy (COT) and HFNC (mean difference [95% CI]; NIV versus COT 5.53% [2.71 to 8.34], NIV versus HFNC 3.58% [0.59-6.57]). On the other hand, when comparing HFNC with COT, a reduction in desaturation was observed, but the effect did not achieve statistical significance (mean difference [95% CI]; HFNC versus COT 1.94% [-0.59 to 4.48]). Additionally, both NIV and HFNC demonstrated a reduced risk of intubation-related complications compared to COT (OR [95% CI], NIV versus COT 0.43 [0.21-0.87], HFNC versus COT 0.49 [0.28-0.88]). However, no significant difference was observed when comparing NIV with HFNC [40].

It was hypothesized that combining HFNC with NIV could offer additional advantages as an innovative preoxygenation approach compared to using each method in isolation. This concept was examined in a small single-center RCT conducted in France, known as the OPTINIV trial [41], where the combination of HFNC and NIV was evaluated against NIV alone. The study involved 50 hypoxemic adult patients requiring intubation for respiratory support. The main causes of respiratory failure were pneumonia and ARDS, representing about 30% and 20% of the study population, respectively. However, it's worth noting that there were subtle differences in two key parameters between the intervention and control groups. Specifically, the SAP II score was higher in the HFNC group (median [IQR]; HFNC combined with NIV 47 [42-49] versus NIV 52.5 [38-57]) and the initial PF ratio was lower in the HFNC combined with NIV group (median [IQR]; HFNC combined with NIV 107 [74-264] versus NIV 140 [83-201]). The application of HFNC together with NIV resulted in a significantly higher minimal SpO_2 during the intubation procedure (median [IQR]; HFNC combined with NIV 100% [95-100] versus NIV 96% [92-99], p=0.029). There were no significant differences in intubation-related complications or ICU mortality.

Preoxygenation with HFNC in neurosurgical patients

The preoxygenation techniques involving a standard oxygen face mask and THRIVE were systematically evaluated in a RCT with 50 patients undergoing elective neurosurgery. After the administration of induction and muscle relaxant agents, a phase known as apneic oxygenation, patients in the standard face mask group received bag-mask ventilation (BMV), while those in the HFNC group continued with the THRIVE device until the endotracheal tube was successfully secured. At the end of preoxygenation, HFNC resulted in a significantly higher mean PaO_2 compared to the face mask group (median [IQR]; HFNC 471 mmHg [429-516] versus face mask 357 mmHg [324-450], p=0.03). However, during the apneic oxygenation phase, PaO_2 in the HFNC group continuously decreased to a level significantly lower than that in the face mask group, which received BMV for apneic oxygenation. It is also important to note that $PaCO_2$ before intubation was significantly higher in the HFNC group (median [IQR]; HFNC 52 mmHg [48-55] versus face mask 43 mmHg [40-48], p=0.0005), which may be a concern in patients with known increased intracranial pressure [42].

Given the variations among studies investigating the role of HFNC as an alternative preoxygenation strategy, including differences in study populations, comparators, methodologies, and assessed outcomes, these discrepancies may contribute to the inconsistent results regarding the efficacy of HFNC in the general population. To date, no specific recommendations have been established for these clinical settings; however, some guidance regarding preoxygenation with HFNC may be provided in certain situations. It is reasonable to assume that HFNC is at least as effective as standard oxygen therapy during preoxygenation in patients with mild to moderate hypoxemia. However, in severely hypoxemic patients, NIV, either alone or in combination with HFNC, might offer greater benefits when compared to HFNC alone. Current evidence still does not support preoxygenation with HFNC in a specific population, including pregnant women and neurosurgical patients [24,25].

APNEIC OXYGENATION

Peroxygenation, often referred to as apneic oxygenation, is the process of administering oxygen without ventilation. It commences after the successful induction of anesthesia and continues until the patient's airway is secured. The primary objective of this strategy is to extend the safe apneic period, providing the anesthesiologist with more time for precise airway management. The physiological mechanism behind this concept involves the passive movement of gases from the nasopharynx or oropharynx to the alveoli, driven by the partial pressure gradient of each gas. During the apneic state, the alveoli absorb an average of approximately 250 ml/min of oxygen, while only 8-20 ml/min of carbon dioxide is excreted. This creates a negative pressure gradient of around 20 cmH_2O, propelling oxygen into the lungs. By continuously delivering oxygen into the pharyngeal space, it is possible to extend the safe apneic time and delay desaturation, even when a patient is in an apneic state. Conventionally, apneic oxygenation is administered through a standard nasal cannula or a nasopharyngeal tube [24,25,43].

HFNC offers several advantages as an apneic oxygenation technique. The device mechanically splints the nasopharynx by providing positive pressure to the upper airway, ensuring a patent air passage between the lungs and the external environment. With the ability to maintain a consistently high FiO_2 and provide a continuous flushing effect, HFNC is an ideal method for ensuring adequate oxygenation while preventing CO_2 accumulation during apneic oxygenation. Additionally, since HFNC is administered through a specially designed cannula, it also enables uninterrupted oxygenation during the ETI process [24,25,43].

In a study by Patel, et al. [44], the impact of the THRIVE technique on apneic oxygenation was investigated in a cohort of 25 patients with underlying cardiorespiratory conditions and known or anticipated difficult airway scenarios, all of whom required general anesthesia for surgical procedures. Their findings revealed that this technique allowed for an average apnea time of 17 minutes without desaturation dropping below 90% and without procedural interruptions due to desaturation or complications related to elevated CO_2 levels. Of particular significance was the observed rate of $ETCO_2$ elevation in the study, measured at 0.15 kPa/min, which was significantly lower than the anticipated rise associated with conventional apneic oxygenation methods (0.35-0.45 kPa/min).

As apneic oxygenation is also applicable during certain surgical procedures, such as airway surgery, studies conducted in this setting could provide insights into the effectiveness of HFNC. A physiological investigation led by Gustafsson, et al. [45]. assessed apneic oxygenation using THRIVE in a group of 31 patients undergoing laryngeal surgery. The study reported an average apnea time of 22.5 minutes (SD = 4.5), with all participants maintaining well-oxygenated status, none experiencing an SpO_2 level below 91%. The mean rates of $PaCO_2$ and $ETCO_2$ increase were 0.24 (SD = 0.05) kPa/min and 0.12 (SD = 0.04) kPa/min, respectively. Notably, apneic oxygenation was prematurely terminated in only one patient before the completion of the surgery due to the patient reaching the discontinuation criteria of a $PaCO_2$ level of 11 kPa. In a separate study by Lyons and Callaghan [46], a case series including 28 patients highlighted the successful application of apneic oxygenation with HFNC during laryngeal procedures. The median apnea time was 19 (IQR 15-24) minutes. Oxygen desaturation was observed in a limited number of cases, with four patients experiencing a single episode of desaturation, falling between 85% and 90% and lasting less than 2 minutes. Following apnea, the median $ETCO_2$ level was 8.2 (IQR 7.2-9.4) kPa, with an average $ETCO_2$ increase of 0.17 (SD = 0.07) kPa/min from an estimated baseline value of 5.0 kPa.

Considering the increased susceptibility to hypoxemia in critically ill patients, particularly during procedures like endotracheal intubation, the application of apneic oxygenation could prove beneficial within this group of patients. Despite numerous studies exploring the application of HFNC in this population, research specifically centered on apneic oxygenation is limited. Additionally, significant heterogeneity exists among these studies regarding participant characteristics, illness severity, preoxygenation and apneic oxygenation techniques, and targeted outcomes. Therefore, special consideration is necessary for interpreting the results of these investigations, even in the context of a meta-analysis. The most recent systematic review and meta-analysis, incorporating seven RCTs examining apneic oxygenation in critically ill patients, revealed that HFNC appeared to show a trend towards a lower incidence of severe hypoxemia ($SpO_2 < 80\%$) and higher SpO_2 levels during procedures compared to standard of care. However, these effects did not reach statistical significance, and the study concluded that HFNC demonstrated noninferiority to the standard of care during ETI in terms of the incidence of severe hypoxemia and the mean lowest SpO_2 [47].

At present, there is still no recommendation for routine use of HFNC during the apneic period based on existing evidence. Nevertheless, HFNC demonstrated the ability to facilitate adequate oxygenation during prolonged apnea without causing CO_2-related complications. Its theoretical advantages and favorable safety profiles, in comparison to conventional oxygenation strategies, make HFNC an appealing option and could potentially be considered a preferred treatment of choice when available [24].

AIRWAY AND ENDOSCOPIC PROCEDURES

Managing the airway and providing respiratory support during airway surgery present substantial challenges for anesthesiologists. It requires a careful balance between minimizing obstruction within the surgical field and ensuring patients receive optimal levels of oxygenation and ventilation. Several oxygenation and ventilatory techniques have been utilized during airway surgery, including mechanical ventilation with tracheal intubation and jet ventilation via various routes. However, each method carries distinct disadvantages and potential complications. Tracheal intubation obstructs the surgical view, often requiring intermittent intubation, causing interruptions in oxygenation and ventilation. This situation increases the risk of hypoxemia, CO_2 retention, tracheal tube-related injuries, and the potential prolongation of the surgical procedure. Similarly, jet ventilation may result in hypoxemia, hypercarbia, the necessity for intubation, and the risk of barotrauma [25,48-50].

Due to its capacity to sustain adequate oxygenation throughout the induction phase of anesthesia without notable CO_2-related complications, even during the apneic oxygenation phase, HFNC emerges as a promising option for airway surgery. At present, evidence regarding the use of HFNC during airway procedures primarily comes from case reports and case series, with only a limited number of RCTs. Furthermore, a substantial degree of heterogeneity exists among these studies, making it challenging to draw definitive conclusions for clinical applications. A systematic review and meta-analysis conducted by Chan and colleagues [50] provided a thorough comparison between HFNC and conventional methods used during airway surgery. The analysis predominantly focused on laryngeal surgery, excluding tracheal reconstruction surgery and bronchoscopy. Among the included studies, HFNC revealed a higher rate of desaturation (median desaturation: 8.1% in the HFNC studies versus 2.25% in the jet ventilation studies) and a more substantial need for rescue intervention (median percentage for rescue intervention: 14.2% in the HFNC studies versus 2.3% in the jet ventilation studies), while also demonstrating a higher peak $PaCO_2$ (median peak $PaCO_2$: 10.2 kPa in the HFNC studies versus 5.65 kPa in the jet ventilation studies). Complications were more prevalent in jet ventilation studies (mean complication rate: 2.2% in the HFNC studies versus 4.0% in the jet ventilation studies), including severe outcomes such as surgical emphysema, pneumomediastinum, and pneumothorax. In comparison to standard ventilation, HFNC significantly reduced the surgical duration (mean difference -4.92 minutes, 95%CI -7.73 to -2.11). However, HFNC was associated with a notably higher peak $ETCO_2$ level (mean difference 2.54 kPa, 95%CI 1.84 to 3.25). Additionally, HFNC exhibited a significantly higher rate of desaturation events (OR 6.58, 95%CI 1.11 to 39.07).

Endoscopic procedures are widely performed in current clinical practice, and more than half of these interventions are conducted under monitored anesthesia with sedation. The increasing popularity of HFNC, attributed to its advantageous physiological benefits, has led to its extended application within this field. Tao, et al. [51] carried out a systematic review and meta-analysis, including 15 small RCTs involving bronchoscopy and gastrointestinal (GI) endoscopy, to evaluate the role of HFNC during endoscopic procedures. Compared to COT, HFNC exhibited a significantly lower risk of hypoxemia ($SpO_2 < 90\%$) (risk ratio = 0.32, 95%CI 0.22 to 0.47) and a notably higher minimum SpO_2 (mean difference = 4.41%, 95%CI 2.95 to 5.86). Patients treated with HFNC also showed a reduced incidence of airway intervention (risk ratio = 0.45, 95%CI 0.24 to 0.84) and fewer events of procedure interruption (risk ratio = 0.36, 95%CI 0.26 to 0.51). However, there were no significant differences observed in end-procedure PCO_2 or the overall intubation rate after endoscopy.

HFNC offers a compelling alternative for oxygenation during bronchoscopy and GI endoscopy compared to COT. Despite its capacity to reduce operation time in airway surgery, HFNC is associated with a higher incidence of desaturation, elevated CO_2 levels, and a greater requirement for rescue intervention. Thus, the implementation of HFNC during airway surgery necessitates effective communication between anesthesiologists and surgeons concerning patient selection and the formulation of a patient-specific rescue plan. High-risk patients should be managed with conventional ventilation via an endotracheal tube for safety reasons [25,50,51].

POSTOPERATIVE AND POST-EXTUBATION PERIOD

It is well documented that HFNC has an established role in ARF to prevent post-extubation respiratory failure. The use of HFNC demonstrates improved oxygenation and lower rates of reintubation compared to COT in critically ill patients with ARF in general [52]. Hernandez and his team [53,54] conducted two separate large RCTs that focused on two distinct subgroups of patients with ARF: those categorized as low-risk and high-risk for reintubation. Their studies revealed that the application of HFNC to extubated patients at low risk for reintubation resulted in a significantly lower reintubation rate compared to COT. However, in patients at high risk for reintubation, typically defined as those aged > 65 years or those affected by chronic cardiac disease, lung disease, or other severe pulmonary disorders, HFNC was proven to be noninferior to NIV. Thille, et al. [55] further investigate the effect of HFNC in high-risk patients by comparing NIV combined with intermittent HFNC sessions against HFNC alone. The results showed that using NIV combined with HFNC after extubation significantly decreased the risk of reintubation compared to HFNC alone in a high-risk population. Nevertheless, the generalizability of HFNC to postoperative patients after extubation is limited, as most of the respiratory failure causes in these studies were attributed to medical conditions, with surgical patients accounting for a smaller proportion, ranging approximately from 2% to 40% [52-55].

Multiple factors associated with surgical and anesthetic procedures significantly affect post-extubation respiratory mechanics and physiology. Anesthetic agents, muscle relaxants, surgery duration, and postoperative pain collectively contribute to postoperative pulmonary complications (PPCs) such as dependent atelectasis, hypoxemia, compromised cough effectiveness, and ineffective secretion clearance. The reported incidence of PPCs ranges from 1% to 23%, varying based on patient-related and surgical factors, with a higher incidence observed following upper abdominal and thoracic surgeries [56-58]. Theoretically, the advantageous features of HFNC could be beneficial in this clinical context, and appropriate use of the device might reduce the occurrence of PPCs [24].

A RCT, known as the OPERA trial [59], conducted by a group of French investigators, assessed the impact of early post-extubation HFNC in patients who underwent abdominal surgery and were at moderate to high risk for PPCs according to the ARISCAT risk score, compared to COT. The study revealed no significant differences in postoperative hypoxemia and PPCs, including the need for reintubation, between the HFNC and COT groups in this patient population. Stéphan, et al. [60] compared the effects of HFNC to BIPAP in post-cardiothoracic surgery patients who were at risk of respiratory failure in a large multicenter randomized noninferiority trial, the BIPOP study. HFNC proved to be noninferior to BIPAP in terms of treatment failure, as assessed by the composite outcome of reintubation, switching to the other study treatment, and premature treatment discontinuation (treatment failure: BIPAP 21.9%, 95%CI 18.0 to 26.2, HFNC 21.0%, 95% CI 17.2 to 25.3, risk difference 0.9%, 95%CI -4.9 to 6.6; p=0.003, noninferior margin = 9%). However, the rate of reintubation alone was similar in both groups (BIPAP 13.7% versus HFNC 14.0%, p=0.99).

Additional insights regarding the application of HFNC during the postoperative period could be derived from systematic reviews and meta-analyses. A study conducted by Boscolo, et al. [6] provided a comprehensive comparison of the effects of various respiratory support devices, including HFNC, NIV, and COT, in a postoperative setting. The analysis indicated that only prophylactic HFNC (OR 0.13, 95%CI 0.04 to 0.45, p=0.001) but not prophylactic NIV (OR 0.27, 95%CI 0.04 to 1.69, p=0.162) decreased the incidence of extubation failure compared with COT in postsurgical patients. Another study by Chaudhuri, et al. [61] demonstrated that the application of HFNC in the intermediate postoperative period significantly decreased the reintubation rate (RR 0.32, 95%CI 0.12 to 0.88, ARR 2.9%, moderate certainty) and was associated with a reduction in the need for escalation of respiratory support (RR 0.54, 95%CI 0.31 to 0.94, ARR 5.8%, very low certainty). Pos hoc subgroup analysis of the study also revealed that obese patients or patients at high risk of postoperative respiratory complications might benefit from HFNC in terms of a reduction in reintubation rate compared to COT (RR 0.14, 95%CI 0.04 to 0.54, p = 0.06). It is noteworthy that the majority of the trials included in this analysis were conducted on cardiothoracic surgery patients.

Despite the considerable heterogeneity among postoperative patients in terms of concerning factors such as patient characteristics, types of operations, and comparators, as well as the conflicting results from several studies, the current ERS clinical practice guidelines on HFNC in ARF also provide recommendations for postoperative patients [5]. In postoperative patients at low risk of respiratory complications, the guidelines recommend the use of either COT or HFNC after extubation (conditional recommendation, low certainty of evidence). Conversely, for postoperative patients at high risk of respiratory complications, the guideline suggests employing either HFNC or NIV after extubation (conditional recommendation, low certainty of evidence). The ERS recommendations regarding the application of HFNC are summarized in Table 2.

Table 1. Mechanisms of action during each stage of perioperative setting. [24]

Mechanisms of action	Preoxygenation	Apneic oxygenation	Airway procedures	Post-extubation
PEEP effect	+	-	+	+
Mechanical splinting of the nasopharynx	-	+	+	+
Dead space wash-out	-	+	+	+
Enhanced mucociliary clearance	-	-	-	+
Reduced WOB	-	-	-	+
Consistent and high FiO_2	+	+	+	+

Table 2. Summary of 2023 ERS clinical practice guidelines: high flow nasal cannula in acute respiratory failure regarding the use of HFNC during post-extubation period. [5]

Population	NIV	HFNC	COT	Recommendations
Nonsurgical patients at **low risk** of extubation failure		+ (HFNC > COT)		Use of HFNC over COT in nonsurgical patients after extubation **(conditional recommendation, low certainty of evidence)**
Nonsurgical patients at **high risk** of extubation failure	+ (NIV > HFNC)			Use of NIV over HFNC for patients at high risk of extubation failure, unless there are absolute or relative contraindications to NIV **(conditional recommendation, moderate certainty of evidence)**
Post-operative patients at **low risk** of respiratory complications after extubation		+ (HFNC or COT)	+ (HFNC or COT)	Use either COT or HFNC in post-operative patients at low risk of respiratory complications **(conditional recommendation, low certainty of evidence)**
Post-operative patients at **high risk** of respiratory complications after extubation	+ (NIV or HFNC)	+ (NIV or HFNC)		Use either HFNC or NIV in post-operative patients at high risk of respiratory complications **(conditional recommendation, low certainty of evidence)**

CONCLUSION

HFNC, delivering heated and humidified high-flow gas at an adjustable FiO_2, offers several benefits to the respiratory system through various mechanisms. It enables the delivery of a more constant and higher FiO_2 gas, provides adequate PEEP to increase EELV, reduces dead space ventilation, and conditions the mixed inspired gas. These combined mechanisms lead to a decrease in the WOB and improve patient comfort. The advantageous features of HFNC could be applied in various perioperative settings. However, research in this field is limited, and the heterogeneity among these studies makes it challenging to provide a clear recommendation for HFNC use in perioperative patients. A comprehensive understanding of the device's working principles and limitations, awareness of the patient's physiological needs during different stages of anesthesia, and meticulous patient selection significantly influence the successful application of HFNC in these populations. Good quality evidence, including well-conducted RCTs and meta-analyses, is still needed to clarify the role of this novel oxygen delivery system during the perioperative period.

ACKNOWLEDGEMENT

None

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