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Review Article

REVIEW ARTICLES

High-flow nasal oxygen therapy in intensive care and anaesthesia

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Abstract

Oxygen therapy is first-line treatment for hypoxaemic acute respiratory failure (ARF). High-flow nasal oxygen therapy (HFNO) represents an alternative to conventional oxygen therapy. HFNO provides humidified, titrated oxygen therapy matching or even exceeding the patients' inspiratory demand. The application of HFNO is becoming widespread in Intensive Care Units (ICUs), favoured by increasing evidence based on numerous studies supporting its efficacy. The mechanisms of action and physiological effects of HFNO are not yet fully understood. Pharyngeal dead space washout, decrease in airway resistance, generation of a positive end-expiratory pressure, and enhanced delivery of oxygen are all alleged to be potential mechanisms. The emerging evidence suggests that HFNO is effective in improving oxygenation in most patients with hypoxaemic ARF of different aetiologies. Notwithstanding the potential benefit of HFNO in the management of hypoxaemia, further large cohort studies are necessary to clarify the indications, contraindications and factors associated with HFNO failure. HFNO may also be valuable in reducing the need for tracheal intubation in the management of post-extubation ARF. In addition, HFNO has been proposed to limit oxygen desaturation by prolonging apnoeic oxygenation during intubation both in ICUs and operating theatres.

Key words: oxygen inhalation therapies; perioperative care; respiratory insufficiency

Oxygen therapy is first-line treatment in the management of hypoxaemic acute respiratory failure (ARF). Different oxygen devices have become available over recent decades, such as low-flow systems (nasal cannula, simple facemask, non-re-breathing reservoir mask) and high-flow systems (Venturi mask).

The choice of a specific device in the management of ARF is based on the severity of the hypoxaemia, the underlying mechanisms, and the patient's breathing pattern and tolerance.[1] In hypoxaemic patients with respiratory distress, who tend to breathe with an open mouth, oxygen therapy is usually delivered *via* a facemask covering both the nose and

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mouth, rather than through a nasal cannula. Critically ill patients often require high-flow devices to meet their oxygen needs.[2] In fact, in tachypnoeic patients with ARF, the peak inspiratory flow rate is usually high and often exceeds the oxygen flow delivered by the traditional oxygen devices.[3,4] A high respiratory rate can generate significant entrainment of room air in the mask and dilution of the inspired oxygen with an insufficient oxygen concentration. The suboptimal humidification of the inhaled oxygen provided by standard bubble humidifiers[5] and the limited and unknown inspiratory oxygen fraction (FIo_2) delivery are additional drawbacks of these devices.

A device utilizing the Venturi effect based on the Bernoulli principle, the so-called Venturi mask, in part overcomes these limitations. Compared with low-flow systems, this device delivers higher flow rates (30-50 total litres min^{-1} of air and oxygen) with FI_{O_2} ranging from 24% to 60%. Nonetheless, with this device, the FI_{O_2} is limited to a nominal 60%: the humidification of the inhaled gas remains problematic because of the insufficient humidification of oxygen by standard bubble humidifiers. This leads to dryness of the airway mucosa and discomfort.[5,6]

High-flow nasal oxygen therapy (HFNO) is an innovative high-flow system that allows for delivering up to 60 litres min^{-1} of heated and fully humidified gas with a FI_{O_2} ranging between 21% and 100%. Recent trials conducted in Intensive Care Unit (ICU) settings indicate that compared with conventional oxygen therapy, HFNO achieves better oxygenation,[6–9] as well as improving patient comfort.[6,7,10,11] Nevertheless, indications and contraindications for HFNO use in critically ill patients have not yet been fully established and there are currently few indications.

In this narrative review, we aim to: (1) describe the potential applications of HFNO in different settings, and (2) provide practical indications and recommendations for facilitating HFNO use. We performed a broad search in PubMed National Library and Embase using the keywords 'high flow nasal' or 'high flow oxygen', limiting our search to adult patients and journals published in English, without any limits to the type of publication. We retrieved 155 studies, and selected those we considered most appropriate and relevant for our purposes. Overall, the authors of this review article are familiar with all the applications of HFNO described and, therefore, their comments are based both on interpretation of the available evidence and personal experience.

HFNO delivery systems: main technical characteristics

HFNO allows for delivering up to 60 litres min^{-1} of gas at 37 $^\circ$C and with an absolute humidity of 44 mg H_2O litres^{-1}. In contrast with all the other systems for oxygen therapy, HFNO enables the administering of FI_{O_2} up to 100%. The physiological effects and action mechanisms of HFNO[6,10,12–21] are illustrated in Table 1.

The administration of HFNO requires the following: high pressure sources of oxygen and air, an air-oxygen blender or a high-flow 'Venturi' system (which permits delivery of an accurate FI_{O_2} between 21% and 100%), a humidifying and heating system for conditioning the gas to optimal temperature (37 °C) and humidity (44mg H_2O litres−1), a sterile water reservoir, a non-condensing circuitry, and an interface.

The two most widely marketed HFNO systems are the Precision Flow by Vapotherm and Optiflow by Fisher & Pykel Healthcare Ltd. (as shown in Fig. 1A and B, respectively). Vapotherm Precision Flow incorporates the air-oxygen blender and oxygen analyser in the humidifier. The flow rate reaches 40 litres min-1. This device contains a cartridge system using membrane technology for water vapour transfer. As a result, water vapour diffuses into the inspiratory stream while heating the gas to the preset temperature (generally 37°C). Moreover, the system utilizes triple lumen 'jacketed'

Table 1 Physiological effects and action mechanisms. HFNO, high-flow nasal oxygen therapy; CO_2, carbon dioxide; PEEP, positive end-expiratory pressure; COPD, chronic obstructive pulmonary disease; PEEPi, intrinsic positive end-expiratory pressure; FI_{O_2}, fraction inspired of oxygen

Physiological effects	Action mechanism
Pharyngeal dead space washout	The high flow generates a reservoir of oxygen that minimizes CO_2 re-breathing, reduces dead space and increases the alveolar ventilation over the minute ventilation ratio.[12]
Reduction of work of breathing	The HFNO system, which fully warms and humidifies inspiratory gas, may significantly reduce the energy requirement (metabolic work) associated with gas conditioning.[12] By providing high gas flows, HFNO reduces the resistance of the upper airway and then decreases the resistive breathing effort.[12,13]
PEEP effect	HFNO is associated with the generation of different values of positive airway pressure (mean values ranging between 2.7 and 7.4 cm H_2O).[14-16] The degree of pressure generated depends on several factors: flow rate, geometry of the upper airway, breathing through the nose or mouth, and size of the cannula in relation to the nostrils. The generated positive airway pressure also depends on the presence and extent of leaks around the nostrils and through the mouth.[14-17] While in acutely hypoxemic patients, the positive airway pressure may determine an increase in end-expiratory lung volume, in COPD it could counterbalance PEEPi determining a reduction in the breathing space effort.[18,19]
Release of a constant fraction of inspired oxygen	The high gas flow reduces the variability of room-air entrainment, also when the respiratory pattern varies.[20] Minimizing oxygen dilution with room air, the delivered FI_{O_2} corresponds closely to the set FI_{O_2}.[21]
Improvement of mucociliary clearance and patient comfort	Air is warmed and humidified, which reduces the viscosity of the tracheobronchial secretions, enhances the mucociliary clearance, reduces dryness of the upper airways and generally improves comfort.[6,10]