High Flow Oxygen in Anaesthesia and Critical Care

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KEY POINTS

- High flow oxygen delivers oxygen at flow rates at or above peak inspiratory flow rates in patients, typically 40-70L/min
- Positive airway pressure is achieved through the high flow rates with approximately 1cmH_2O increase for each 10L/min flow rate above 30L/min
- Carbon dioxide rise during apnoea is less with high flows (40-70L/min) than with conventional oxygenation during apnoea
- Apnoeic time can be safely extended using high flow nasal oxygen (HFNO) for 22 minutes
- High flow oxygen has a role in hypoxaemic respiratory failure in intensive care management of patients

INTRODUCTION

The delivery of oxygen to patients is conventionally via face masks or nasal cannula. Typically they deliver a low flow of non-humidified oxygen at up to 15 L/min, often without a defined fraction of inspired oxygen (FiO_2) concentration. These conventional oxygen delivery devices fail to supply oxygen at high enough flow rates to match a patient's peak inspiratory flow rate. The patient therefore entrains room air with inspiration and does not get the desired oxygen concentration (1,2).

High flow nasal oxygen (HFNO) is delivered through specialised nasal cannula and can achieve a flow rate of up to 70 L/min and FiO2 near 100% (1). Its use in intensive care for spontaneously breathing patients is well established and novel uses are emerging in anaesthesia. Studies supporting its application in this field include the THRIVE (Transnasal Humidified Rapid Insufflation Ventilatory Exchange) study in apnoeic patients and the STRIVE Hi (SponTaneous Respiration using IntraVEnous anaesthesia and High-flow nasal oxygen) study in spontaneously breathing patients under anaesthesia (3,4).

The combined use of low-flow nasal cannula and facemask for apnoeic oxygenation has been shown to increase time to desaturation during intubation attempts. (Figure 1, 2). This remains an important technique especially in resource limited settings where equipment for high flow may not be available.

This tutorial aims to provide a short overview for the current use of high flow nasal oxygenation in anaesthesia and critical care practice.

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TAKE ONLINE TEST

Figure 1. The apnoeic window can be extended by providing 15 L/min through a face mask and nasal cannula during preoxygenation. The use of nasal cannula may also be combined with face mask oxygenation via the anaesthetic machine or transport breathing circuits (e.g. Mapleson C or F) .Image reproduced with permission from https://epmonthly.com/article/no-desat/

DELIVERY OF HIGH FLOW OXYGEN

High flow oxygen is commonly administered through wide bore high flow nasal cannula (HFNC). The delivery system uses a calibrated high flow meter and in some devices, a control system to determine inspired oxygen concentration (Figure 3 & 4).

Variable FiO_2 is achieved via a Y-connector and two flow meters or calibrated proportioner valve blenders (2). Humidification and heating of oxygen is a key component in allowing such high flow rates to be tolerated by patients. Various manufacturers have different ways of achieving this but relative humidification of 95-100% and gas temperatures of 33-43°C are possible (1). Humidification is provided through vapour cartridges, bubble humidifiers or heated plates. The tubing connecting the flow control to the patient may be heated to prevent condensation within it. Inspiratory connections are 15mm or 22mm in diameter, allowing connection to a tracheostomy if indicated. Nebulised drugs can be delivered through aerosol devices integrated into the HFNC delivery system (1).

PHYSIOLOGICAL BENEFITS OF HIGH FLOW NASAL CANNULA

Increase in apnoeic time and carbon dioxide clearance

Anaesthetists can extend the safe apnoea time through pre-oxygenation; but without ventilation, patients desaturate within minutes. Transnasal Humidified Rapid Insufflation Ventilatory Exchange (THRIVE) via HFNC describes a technique for apnoeic oxygenation and its use has successfully extended the apnoeic window by up to 65 minutes, while reducing the rate of carbon dioxide rise (4). This has also been found to be useful in the management of patients with difficult airways (5). The THRIVE study included 31 patients with a mean apnoea time of 22.5 minutes. The range of apnoea time was 11 to 33 minutes with surgery completed successfully in 30 patients. One patient underwent subsequent jet ventilation after discontinuation criteria were met ($PaCO_2 > 11$kPa).

Figure 2. Oxygen continues to be delivered via nasal cannula in the apnoeic period during intubation. Reproduced with permission from https://epmonthly.com/article/no-desat/

Figure 3. High flow nasal cannula connected to patient. Reproduced with permission from https://www.armstrongmedical.net/product/point-blender/

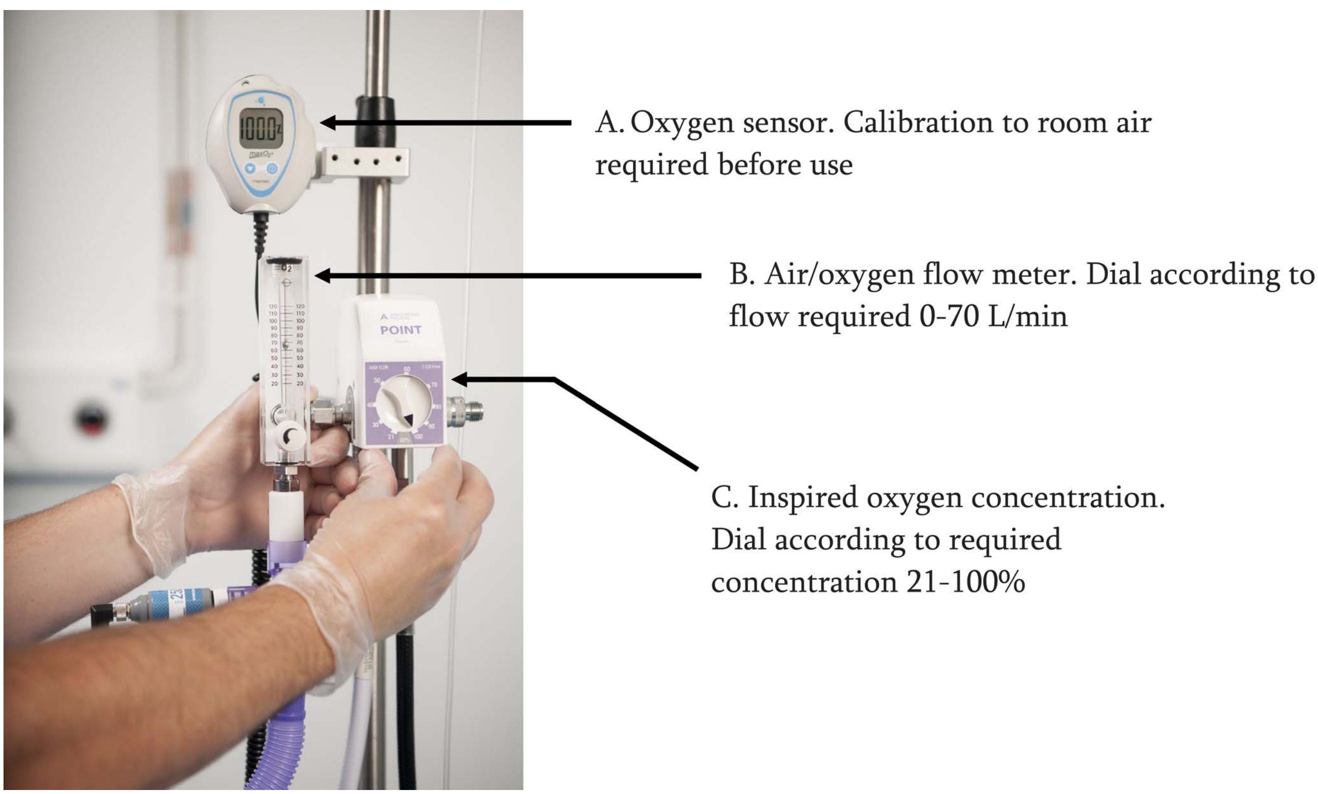

Figure 4. Calibrated high flow meter in addition to control dial for control of inspired oxygen concentration. Reproduced with permission from https://www.armstrongmedical.net/product/point-blender/

Apnoeic oxygenation describes the process of aventilatory mass flow of oxygen without spontaneous respiration or mechanical ventilation. Oxygen is driven into the lungs by the negative pressure gradient created by the difference between alveolar oxygen removal and carbon dioxide excretion (4,6). Oxygenation can be achieved by any means of oxygen delivery device as long as a patent airway is maintained.

Carbon dioxide clearance, subsequent acidosis and fatal arrhythmias remain a problem if lower flow delivery devices are used. The exact mechanism of carbon dioxide clearance through THRIVE is unclear, but supraglottic turbulence generated by HFNC and cardiogenic oscillations are thought to play a role (7).

Gas conditioning: heating and humidification

HFNO warms and humidifies gases so the high flow rate is more tolerable to awake and spontaneously breathing patients (8). By warming and humidifying the gas, high flow systems reduce the metabolic cost of respiration (9). Humidification of gases helps to prevent drying of secretions, which can reduce cilia function and lead to mucus plugging, atelectasis and hypoxia (10).

Fixed FiO2 delivery and dead space washout

Conventional oxygen therapy delivers gas flow rates much lower than peak inspiratory flows due to entrainment of room air and hence dilution of FiO_2. Studies have demonstrated that measured FiO_2 within the nasopharynx is much closer to delivered FiO_2 in patients receiving high flow nasal oxygen implying minimal room air entrainment (2,11). Delivered oxygen concentration may also be improved by washout of dead space gas, thereby creating an oxygen reservoir within the patient (1,2)

Positive Airway Pressure

The respiratory tree from the nasopharynx to alveoli provides a degree of resistance to the flow of gas. The nasopharynx generates a variable resistance to gas flow which increases on inspiration, as the walls of the nares are drawn in. Conventional Continuous Positive Airway Pressure (CPAP) overcomes this resistance by providing a distending pressure that HFNC aim to replicate (9). As a result, the reduction in atelectasis and lobar collapse improves ventilation/perfusion (V/Q) ratio (2)

In 2013 Parke et al showed that HFNO supplies positive airway pressure of approximately $1cmH_2O$ per 10L/min flow rate. Flow rates of 30L/min, 40L/min and 50L/min gave peak expiratory pressures of 3.01 cmH_2O, 3.81 cmH_2O and 4.86 cmH_2O respectively. Of note, at flow rates of 30L/min, when patients exhale the airway pressure returned to zero and so the device does not deliver positive pressure throughout the respiratory cycle (11)However, the airway pressure delivered by HFNO demonstrates pressure variability during different phases of respiratory cycle (11, 12) unlike CPAP which gives a continuous positive airway pressure. Therefore, CPAP oxygen delivery system should be considered separate to HFNO.

HFNO IN ANAESTHESIA PRACTICE

There are various methods for employing HFNC around the time of intubation. HFNC can be used throughout the period of pre-oxygenation with flow rates of 40L/min while the patient is awake and increasing up to 70L/min once anaesthetised. This was the protocol used in the apnoeic oxygenation study by Gustafsson et al (5). The HFNC then remains in situ during laryngoscopy and intubation. An alternative method involves using conventional methods of pre-oxygenation via bag valve mask, then switching to HFNC for laryngoscopy. This method allows the anaesthetist to feel confident they can mask ventilate the patient prior to intubation.

Difficult Airway Management

Managing difficult airways is stressful. Repeated laryngoscopy attempts can lead to airway trauma, oedema and bleeding especially in patients with a friable airway tumour or other pathology. HFNO affords the ‘luxury of time’ to move to another method of securing the airway while maintaining oxygenation and reduces the possibility of morbidity from hypoxic brain injury in these difficult cases.

Two recent case reports in the *Journal of Head and Neck Anaesthesia* describe repeated attempts by anaesthetists and surgeons to secure oral intubation in a patient with a difficult airway (12). During both cases, HFNO provided oxygenation until emergency tracheostomy was performed. In one case, total apnoea time was 30 minutes.

Other uses include oxygenation during awake emergency tracheostomy, awake fibreoptic intubation (10) or awake videolaryngoscopy. During emergency awake tracheostomy, HFNO can extend the apnoea window, provide a small amount of positive airway pressure and reduce a patient’s work of breathing. It is important to be aware of the airway pathology as HFNO will not work if the upper airway is completely obstructed and barotrauma is a possibility in those patients with significant airway stenosis.

Obstetric anaesthesia and airway management in obese patients

Obese patients and obstetric patients have increased risk of difficult airways. Both groups may be at risk off aspiration, have reduced time to desaturation and potentially difficult laryngoscopy. The Obstetric Anaesthetists Association (UK) and Difficult Airway Society (UK) guideline in 2015 recommends consideration of nasal oxygenation with 5L/min oxygen via simple nasal cannula commencing before preoxygenation. The guideline also mentions a potential role of apnoeic oxygenation via HFNO based on evidence from non-obstetric setting in its document concerning Safe Obstetric General Anaesthesia (13).

Its role in obstetric patients undergoing general anaesthesia could potentially help to avoid morbidity to mother and baby by reducing time to desaturation during intubation. It also can be used as an adjunct to assist alveolar recruitment post extubation, thereby reducing incidents of re-intubation caused by hypoxia (6)

Tubeless field surgery

The need to provide an unobscured surgical field while maintaining oxygenation and anaesthesia during ENT procedures can be challenging to the anaesthetist, especially if the procedure involves the larynx and upper airway (e.g. vocal cord biopsy, laser therapy, balloon dilatation or subglottic stenosis). Oxygenation in this situation is traditionally maintained through jet ventilation using a rigid bronchoscope, trans-tracheal catheter or jet ventilation catheter.

Using HFNO enables a surgeon to perform ENT procedures with an unobstructed view and without interruptions from jet ventilation. Patients can be spontaneously breathing or apnoeic with full muscle relaxation, while anaesthesia is maintained with total intravenous anaesthesia.

There are successful case reports of laser therapy use during tubeless field surgery with HFNO. Close communication is required between surgeon and anaesthetist to ensure inspired oxygen concentration is turned down to 21% before and during laser use. This limits the use of HFNO in conjunction with lasers to devices that have a variable oxygen concentration delivery control. Constant vigilance is required by the whole theatre team. Standard operating procedures or checklists for complex procedures such as this may improve safety by ensuring oxygen is reduced at the appropriate time.

Booth et al showed that SponTaneous Respiration using Intravenous Anaesthesia and High flow nasal oxygen (STRIVE-Hi) could increase the margin of safety in tubeless field surgery. Compared to THRIVE, which relies on apnoeic ventilation, the rate of CO2 increase is even lower (0.15kPa/min in THRIVE study compared to 0.03kPa/min in STRIVE-Hi) and it is superior to THRIVE in maintaining oxygenation in patients with high BMI (3). Maintaining ventilation with propofol in this situation suppresses laryngeal reflexes while enabling high oxygen flows.

Vigilance should be high during use of HFNO during tubeless field surgery. There is potential for the suspension laryngoscope to obstruct the airway and a risk of airway fire especially if inspired oxygen concentration is not turned down at appropriate points when laser or diathermy use is planned. Anaesthesia needs to be maintained using TIVA and therefore experience of this anaesthetic technique is mandatory before considering HFNO use in this field. A further problem is the inability to monitor end tidal carbon dioxide concentration when HFNO is in use.

Respiratory support during procedural sedation

Conscious sedation during procedures such as bronchoscopy, gastroscopy or colonoscopy often requires supplemental oxygen due to the respiratory depressive effects of sedative agents. The scope for HFNO use during procedures could span a variety of specialties, novel uses for high flow nasal cannula oxygenation have been reported for awake craniotomies (14) and as an adjunct to regional anaesthesia for a number of surgical procedures.

HFNO could provide a better method of oxygenation compared to simple devices in these situations. The addition of a small amount of positive pressure to the upper airway may be beneficial in maintaining airway patency. And HFNO may provide a margin of safety should patients become apnoeic during sedation.

High Flow Nasal Oxygen in Critical Care

The Royal College of Anaesthetist National Audit Projects (NAP) aim to investigate rare complications associated with anaesthesia in the UK. The 4th NAP reported 1 in 4 major airway events happened in the emergency department or critical care when an emergency intubation is often complicated by an acutely unwell patient with high metabolic demand for oxygen (17)

A meta analysis of 1658 patients by Silva et al (2017) (16) looked at comparative studies of preoxygenation followed by apnoeic oxygenation versus traditional preoxygenation alone during intubation. Subset data analysis was performed on the critically ill patient group who required intubation in the Emergency department and Intensive Care. Apnoeic oxygenation was provided in most cases by high flow oxygen devices and intubations were performed by a variety of trainees and experienced airway specialists. The outcome of the meta analysis showed that fewer patients desaturated to less than 93% when using apnoeic oxygenation (OR 0.66), Furthermore, the lowest recorded oxygen saturation was lower in standard preoxygenation compared to apnoeic oxygenation (16). These findings support the use of high flow oxygen during intubation of acutely unwell patients.

Hypoxia unresponsive to conventional oxygen therapy has classically resulted in patients placed on non-invasive ventilation (NIV) or CPAP as a method to avoid need for intubation. Frat et al 2015 (19) undertook a 3-arm study comparing HFNO to standard therapy or NIV at reducing intubation rates in patients with hypoxaemic respiratory failure. The study of 310 patients showed the HFNO group had the lowest rate of intubation. HFNC has been shown to be non-inferior to NIV in terms of respiratory support post extubation or in preventing re-intubation (17,18).

There is emerging evidence that HFNC is also of use in hypercapnic respiratory failure (20). Yuste et al (2019) undertook a prospective observational study evaluating the use of HFNO in patients with mild respiratory acidosis (pH $>$ 7.25). 30 patients with hypercapnia respiratory failure were treated with HFNO. 4 patients required subsequent intervention of NIV or intubation but the remains 26 patients normalised their pH after 24 hours. Patients were excluded if other organ systems were compromised by the acute illness indicating the need for appropriate patient selection for HFNO in these patients.

LIMITATIONS

Oxygenation using HFNC in any setting cannot work without a patent airway. Desaturation may be the first sign of an obstructed airway if airway patency is not actively maintained. Equipment failure must also be considered should desaturation occur with rapid checks made to correct any failure. If HFNO is used during rapid sequence induction or elective intubation, a jaw thrust must be maintained while the anaesthetist awaits adequate muscle relaxation prior to securing the airway.

Apnoeic oxygenation HFNO does not prevent a climb in the patients arterial carbon dioxide. The rate of carbon dioxide rise with THRIVE is lower than in apnoeac oxygenation through low flow oxygen (4). Rising carbon dioxide levels during apnoea can lead to an increase in heart rate, blood pressure and cerebral blood flow (21). There are transcutaneous methods of measuring carbon dioxide (as used in the THRIVE trial) which may become increasingly available and widespread in the future.

SUMMARY

HFNO allows safe extension of apnoeic times while maintaining oxygenation. The heating and humidification appear to facilitate patient tolerance while also reducing work of breathing. Carbon dioxide build up is at a lower rate than with other forms of apnoeic oxygenation attributed to the aventilatory mass exchange of gas molecules.
The use of high flow oxygenation is expanding within anaesthesia and critical care. As popularity increases it is important for the anaesthetist to have an understanding of the physiological basis of this technique and the equipment for safe use.

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