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A guide to

High-flow nasal oxygen therapy in airway management

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History of high-flow nasal oxygen

Administration of oxygen at high flow rates has historically been limited by the drying effects on nasal and oropharyngeal mucosa. Over the past few decades devices that deliver heated and humidified oxygen at high flows through a nasal cannula have been developed and the use and applications of these has increased considerably in recent years.

The first commercial system, the Transpirator MT-1000, was introduced in 1987. This could produce up to 20 litres/min at body temperature pressure saturated and was intended to enhance clearance of secretions in patients cystic fibrosis (Waugh, 2006). Innovative devices can now deliver higher flow rates of heated and fully humidified gas ranging from 30–120 litres/min, via purpose-built nasal cannula, with a fraction of inspired oxygen (FiO_2) ranging from 21–100% (Millette et al, 2018). The gas source (air/oxygen blender, ventilator or turbine) is connected via an active heated humidifier to a nasal cannula and allows FiO_2 adjustment independently from the flow.

High-flow nasal oxygenation has successfully been used, predominantly in intensive care (Parke et al, 2011) but also in emergency department settings (Lenglet et al, 2012), to treat acute respiratory failure (Roca et al, 2010; Rello et al, 2012), to prevent postoperative atelectasis and to alleviate dyspnoea in acute heart failure (Roca et al, 2013). There is now emerging evidence for the use of high-flow nasal oxygen as a technique to increase the apnoeic window in the context of tracheal intubation in both anaesthetics and intensive care (Gustafsson et al, 2017). This technique was described by Patel and Nouraie (2015) as THRIVE (Transnasal Humidified Rapid Insufflatory Ventilatory Exchange).

Physiology of high-flow nasal oxygen

The physiology of high-flow nasal oxygen and its effects are outlined in *Table 1*.

The POINT system for high-flow nasal oxygen

Peri-Operative Insufflatory Nasal Therapy (POINT) by Armstrong Medical (*Figure 1a*) has the following characteristics:

- Flow range: 20–120 litres/min
- High-flow nasal oxygen 20–80 litres/min
- Face mask continuous positive airway pressure >80 litres/min
- Oxygen concentration: 21–100% FiO_2

This system uses the AquaVENT heater humidifier (*Figure 1b*) which provides airway temperature settings 34–39°C. The consumables used by POINT include:

- Extra long heated breathing system 1.8 m protected by BioCote antimicrobial technology
- Low profile high-flow nasal oxygen cannula with bilateral positioning (*Figure 1c*)
- Can be used with face mask continuous positive airway pressure preoxygenation
- Easily adapted for face mask continuous positive airway pressure.

Clinical applications of high-flow nasal oxygen

Historically, high-flow nasal oxygen was principally used for neonates, but its use has now extended to adult therapy in anaesthesia and intensive care, backed by an ever-increasing evidence base (Ward, 2013). *Table 2* lists the advantages and disadvantages of the use of high-flow nasal oxygen, and *Table 3* lists the contraindications to its use.

Anaesthesia and resuscitation setting

Pre-oxygenation for intubation or rapid sequence induction

High-flow nasal oxygen improves preoxygenation before intubation and maximises apnoea time before desaturation (Mir et al, 2016).

A major advantage of high-flow nasal oxygen is that it can be continued while airway instrumentation takes place in contrast to face mask oxygen which must be removed following induction of general anaesthesia.

Preoxygenation with high-flow nasal oxygen may be particularly beneficial in patients with a reduced functional residual capacity or increased metabolic demand for oxygen, such as obstetric patients, bariatric patients or patients with sepsis.

Figure 1. **a.** Peri-Operative Insufflatory Nasal Therapy (POINT). **b.** The AquaVENT heater humidifier. **c.** Aquanase high-flow nasal oxygen cannula.

Table 1. The physiology of high-flow nasal oxygen	
Effects	**Mechanism of action**
Nasopharyngeal dead space washout	■ High-flow nasal oxygen flushes the dead space of the nasopharyngeal cavity (the high flow generates a reservoir of oxygen that minimizes carbon dioxide re-breathing), thereby reducing overall dead space and resulting in alveolar ventilation as a greater fraction of minute ventilation (Dysart et al, 2009) ■ This can lead to decreased arterial carbon dioxide concentration (Nillius et al, 2013) ■ Respiratory effort becomes more efficient ■ Thoracoabdominal synchrony improves
Reduction of work of breathing	■ By administering an inspired gas with a relative humidity of 100% at 37°C (equivalent to 44 mg/litre absolute humidity) the energy requirement (metabolic work) associated with gas conditioning is significantly reduced (Dysart et al, 2009) ■ High-flow nasal oxygen minimizes the nasopharyngeal inspiratory resistance by providing nasopharyngeal gas flows that match or exceed a patient's peak inspiratory flow. This change in resistance translates to a decrease in resistive breathing effort (Dysart et al, 2009)

Positive end expiratory pressure effect	■ High-flow nasal oxygen is associated with the generation of positive airway pressure but to varying degrees. The pressure generated depends on:
	  ■ Flow rate – several studies have shown the positive relationship between flow and mean airway pressure, in particular, work by Groves and Tobin (2007) and Parke et al (2009)
	  ■ Whether the mouth is closed or open
	  ■ The size of the nasal cannula in relation to the nostrils
	  ■ Geometry of the upper airways
	■ Positive pressure aids with lung recruitment and reduction in the ventilation–perfusion mismatch within the lungs
	■ End-expiratory lung volume is greater with high-flow nasal oxygen than with low oxygen therapy

Constant fraction of inspired oxygen	■ The high gas flow reduces the variability in the fraction of inspired oxygen (FiO_2) delivered as it reduces the entrainment of ambient air thus minimizing subsequent dilution of FiO_2 (Sim et al, 2008)
Improvement of mucociliary clearance and patient comfort	■ The humidification and warming of gas delivered to the patient reduces the viscosity of secretions and thus can facilitate and enhance mucociliary clearance (Dysart et al, 2009) ■ Reduction in the dryness of the upper airways generally improves comfort for patients
Apnoeic oxygenation	■ During apnoea, diffusion of oxygen from alveolar to the capillaries continues (250 ml/min in an average adult), while carbon dioxide diffusion from the capillaries into the alveoli decreases to 20 ml/min. This results in decrease in lung volume and alveolar pressure. This pressure gradient creates a ventilatory mass flow from the nasopharynx to the alveoli in the presence of patent airways ■ This can be used clinically and high-flow nasal oxygen has been shown to increase the apnoeic oxygenation time. Patel and Nouraei (2015) showed that the median apnoea time was 14 minutes (interquartile range 9–19 minutes; range 5–65 minutes). Gustafsson et al (2017) found a mean apnoea time of 22.5 minutes

Table 2. Advantages and disadvantages of high-flow nasal oxygen	
Advantages	Comfortable oxygen delivery, reducing likelihood of treatment failure
	Easy to implement: soft nasal cannulae are usually well tolerated
	A broad range of flows and oxygen concentrations can be delivered. This provides versatility and allows titration according to patient response
	Better mucocilliary clearance and reducing risk of infection (Kilgour et al, 2004)
	Reduction in work of breathing
	Easier oral care
	Nursing workload is reduced as there is less attendance time and no need to change between multiple devices and interfaces in comparison to face mask systems
	Delivery of accurate fraction of inspired oxygen (FiO_2)
Disadvantages	Some patients cannot tolerate high flows as a result of nasal discomfort
	Nasal mucosa irritation
	Pneumothorax risk in neonates
	Oxygen is not humidified at low flow, thus dry nose, dry throat and nasal pain are common at low flows

From Nishimura (2015); Renda et al (2018)

Difficult airway

THRIVE (Transnasal Humidified Rapid-Insufflation Ventilatory Exchange; Patel and Nouraei, 2015) is a technique using high-flow nasal oxygen to increase the apnoeic window in patients with difficult airways undergoing general anaesthetic. Patel and Nouraei (2015) pre-oxygenated patients positioned at a 40° incline with high-flow nasal oxygen at a rate of 70 litres/min for 10 minutes. Patients then received total intravenous anaesthesia and neuromuscular blockade. Jaw-thrust was performed immediately the patient became unconscious and was maintained throughout the apnoeic period. The patient's angle of inclination was reduced to 20° for laryngoscopy. Nasal oxygenation was maintained at 70 litres/min until a definitive airway was secured. There were no desaturations below 90%, despite an average apnoea time of 17 minutes and no patients developed cardiac arrhythmias or other complications suggestive of carbon dioxide toxicity.

Table 3. Contraindications to use of high-flow nasal oxygen
Consciousness disorder if aspiration concern
Agitated or uncooperative patient
Facial injury (risk of airway soiling)
High secretion load
Patients at high risk of aspiration
Base of skull fractures (risk of pneumocephalus)
Complete or impending airway obstruction

Awake fibreoptic intubation

The features of high-flow nasal oxygen allow high FiO_2 under positive pressure to be delivered continuously throughout an oral or nasal awake fibreoptic intubation. A fibreoptic endoscope can be manoeuvred alongside the soft nasal cannulae. The humidification of the gases leads to greater patient comfort and a higher tolerance compared to conventional methods.

An observational series by Badiger et al (2015) found that high-flow nasal oxygen is well tolerated, improves oxygenation, and may prevent desaturation arising as a result of apnoea or hypoventilation.

Procedural oxygenation

This can be used for bronchoscopy or dental extraction. For sedation, a jaw-thrust is usually required once airway reflexes are obtunded to allow for passive oxygenation.

Ear nose and throat surgery

Short procedures such as microlaryngoscopy may be managed using high-flow nasal oxygen. Provided the airway is patent throughout, apnoea times of more than 20 minutes can be achieved with maintenance of oxygenation and only relatively small increases in arterial carbon dioxide levels. Care should be taken to reduce the FiO_2 if laser surgery is anticipated.

High-flow nasal oxygen can increase the time to desaturation in patients with airway stenosis and stridor through increased FiO_2, positive end expiratory pressure and decreased work of breathing.

Care should be taken in severe airway stenosis where there is limited gas entrainment. High-flow nasal oxygen can be a useful adjunct but cannot maintain adequate oxygenation alone for long periods in such circumstances.

Extubation and post surgery

High-flow nasal oxygen improves oxygenation following extubation and can potentially decrease the incidence of respiratory complications and reintubation.

Intensive care setting

Acute hypoxic respiratory failure

The use of high-flow nasal oxygen increases oxygen saturation, arterial oxygen partial pressure and reduces the frequency of breathing (Lenglet et al, 2012).

The FLORALI Trial (Frat et al, 2015) demonstrated the effectiveness of high-flow nasal oxygen in a well-defined subset of patients in acute respiratory failure with hypoxaemia and no hypercapnia. There was a significant improvement in 90-day mortality in patients who received high-flow nasal oxygen therapy compared to those given either non-invasive ventilation or standard oxygen therapy. Patients in the high-flow nasal oxygen group with severe hypoxaemia had a significant reduction in re-intubation rate. The authors suggested that use of high-flow nasal oxygen may have driven the mortality benefit.

Adult respiratory distress syndrome

There is currently little evidence supporting the use of high-flow nasal oxygen in adult respiratory distress syndrome (Demoule et al, 2016; Miyakawa et al, 2017).

Post-extubation (post-surgical) and preventing post-extubation respiratory failure

Several randomized controlled trials (Maggiore et al, 2014; Rittayamai et al, 2014) have demonstrated that high-flow nasal oxygen can improve dyspnoea and physiological parameters in extubated patients compared with conventional oxygen therapy.

Acute cardiogenic pulmonary oedema

There are studies emerging of patients successfully treated with high-flow nasal oxygen in the intensive therapy unit setting. However, continuous positive airway pressure remains the first-line treatment of choice for hypoxaemic patients with acute cardiogenic pulmonary oedema (Carratala Perales et al, 2011; Roca et al, 2013).

Practical recommendations for high-flow nasal oxygen in anaesthesia

Appropriate choice of patient

Currently there are no published guidelines of absolute contraindications to high-flow nasal oxygen. It has been suggested that contraindications to the use of high-flow nasal oxygen are similar to those for non-invasive ventilation (Renda et al, 2018) (*Table 4*). There are some situations where standard non-invasive ventilation would be contraindicated but high-flow nasal oxygen can be used effectively, such as in patient apnoea and for airway laser use. It is likely that intrathoracic pressure is lower in high-flow nasal oxygen than standard non-invasive ventilation (depending on pressure settings), thus it may be better tolerated in patients with cardiovascular instability.

Appropriate setting

Consideration should be given to where best to store the high-flow nasal oxygen system. Locations where emergency use is likely include the emergency department, operating theatres and maternity unit.

If intended to be used as an emergency airway adjunct, the system, including all disposable parts, should be set up in a suitable location. Most devices use a heated water chamber. The system cannot be left primed with water because of the risk of bacterial growth, but water should be stored with the system ready to use.

Appropriate staff

If relied upon for emergency use, there must always be staff available who are trained in the set up and use of the high-flow nasal oxygen system.

Regular staff training, particular high-fidelity simulation, can effectively maintain skills if the system is rarely used.

Patient monitoring

Continuous monitoring, including cardiovascular parameters and oxygen saturation, is essential.

It is not possible to monitor real-time end tidal carbon dioxide when using high-flow nasal oxygen.

- The partial pressure of carbon dioxide in arterial blood ($PaCO_2$) can be measured by peri-procedural blood gas measurement
- Continuous cutaneous carbon dioxide monitoring is not generally available in most institutions
- An approximation of end tidal carbon dioxide can be made by intermittent application of a face mask to the patient and manually insufflating the lungs with an end tidal carbon dioxide monitor attached to the circuit. This technique may be useful in multi-stage ear nose and throat procedures.

Correct choice of nasal cannulae

The cannulae are usually made from a soft silicon material. Devices such as the POINT system use an elasticated harness to maintain cannulae position. They should not occlude the nostrils.

It is easy to dislodge the nasal cannulae during use and the anaesthetist may need to reposition them during the procedure.

Flow rates

The authors have found that awake patients tolerate a flow rate of 30 litres/min well. This is their default starting flow rate. Flows may be increased or decreased according to response or tolerance.

During induction of anaesthesia, flow rates are increased to 80 litres/min once the patient is unconscious.

Inspired oxygen concentrations

FiO_2 is adjusted to provide satisfactory oxygen saturation of arterial blood (SaO_2). The authors routinely start at 100% and then reduce according to oxygen saturations.

During laser airway surgery, the FiO_2 is reduced to 21%. The high-flow nasal oxygen systems are versatile. When using POINT, alterations to FiO_2 are near instant because of the high flow rates. This allows rapid adjustment of FiO_2 during laser cases so patients can be easily re-oxygenated if saturations drop during the case.

Temperature setting

The authors routinely set the system temperature at 37°C to maximize humidification without thermal injury to the airway.

Recommendation for use of high-flow nasal oxygen in intensive therapy unit

1. Start at a flow rate of 30 litres/min and increase according to response/tolerance.
2. If a satisfactory SaO_2 and oxygen partial pressure are achieved in combination with a reduction in respiratory rate and acceptable $PaCO_2$, the FiO_2 should be reduced by approximately 5–10%.

The flow rate may be reduced by 5 litres/min. Reassessment after 1 hour may lead to further reduction in respiratory support (Renda et al, 2018).

3. Consider weaning from high-flow nasal oxygen when flow rates are <25 litres/min and FiO_2 <35%. Patients should be weaned onto face mask humidified oxygen.
4. If there is no improvement or a deterioration after 1 hour, treatment escalation must be considered – options include face mask non-invasive ventilation or tracheal intubation.
5. The authors have found the system effective in avoiding intubation in patients with stridor.

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