Apneic Oxygenation and High Flow

Ayten Saracoglu¹*, Halime Hanim Pence², Mehmet Yilmaz³ and Kemal Tolga Saracoglu³

¹Department of Anesthesiology and Reanimation, Marmara University, School of Medicine, Turkey
²Department of Medical Biochemistry, Health Sciences University, Turkey
³Department of Anesthesiology and Reanimation, Health Sciences University, Turkey

*Corresponding author: Dr. Ayten Saracoglu, Assoc. Prof. MD, Department of Anesthesiology and Reanimation, Marmara University Medical School Hospital, Fevzi Cakmak Mh. Muhsin Yazicioglu Cd. No: 10, Pendik, Istanbul, Turkey, Tel: +902166570606

Abstract
Prevention and minimizing serious complications during difficult airway management is an important goal for anesthesia providers. Using the high flow cannula oxygenation systems it is possible to improve the clinical outcomes, increase patient safety and reduce the rate of complications. A possible mechanism of this method can be explain by ‘Aventilatory Mass Flow’ which is a physiological phenomenon. Several methods can be used to implement apneic oxygenation such as nasopharyngeal catheter, nasal cannula, face mask, Venturi mask, transtracheal endobronchial catheters, dual blade laryngoscopes and High Flow Nasal Cannula Oxygenation (HFNCO) systems. However each method has some restrictions. In this review we aim to focus on the important features of HFNCO systems including the indications, contraindications and possible complications.

Keywords
Apneic oxygenation, Aventilatory mass flow, High flow

Introduction
Cardiovascular collapse, anoxic brain injury or death are some of the results of serious complications that may occur during difficult airway management. Minimizing the risk of these complications is only possible by improving airway management strategies. Apneic oxygenation is a beneficial method adopted incrementally for this purpose. Actually this is historically an old method, first defined by German Anesthesiologists in 1905 [1]. Holmdahl [2] defined apneic diffusion oxygenation during bronchoscopies in 1956. Frumin, et al. [3] demonstrated that it was possible to maintain high levels of oxygen saturation for 18 to 55 minutes without ventilation. Following these reports, Weingart and Levitan [4] introduced apneic oxygenation to prevent desaturation. And popularity of this method has been peaking in this century. Fick principle explains uptake and consumption of O₂ by peripheral tissues. Cardiac output and oxygen rates in arterial and venous compartments play major role in this equation. A normothermic adult human consumes 3 mL/kg oxygen. Critical threshold of oxygen consumption is 250 mL/min. Oxygen consumption increases with increased alveolar ventilation in parturients [5].

During apnea, PaO₂ decreases as O₂ gets removed from lungs. As long as hemoglobin keeps being oxygenated in lungs, saturation levels remain over 90%. When oxygen the level in lungs start decreasing, PaO₂ is around 45-50 mmHg at this point. Denitrogenation of functional residual capacity (FRC) may increase oxygen capacity of lungs. This is possible by increasing oxygen percentage in breathing gas (FiO₂). Also applying continuous positive airway pressure (CPAP) and elevating patient’s head to 25-30 degrees prevents atelectasia and improves FRC respectively.

Safe apnea period is the time from discontinuation of ventilation to the beginning of desaturation (SpO₂ < 90%). Anesthesiologists have limited time to provide safe airway when patients are unconscious. This period is called “apneic window”. Decrease in PaO₂ levels causes rapid deceleration in SaO₂ below this level. Inappropriate preoxygenation, airway occlusion, pulmonary shunt, critical diseases, obesity, pregnancy and pediatric patients are some risk factors of short apneic win-
dow. Time from succinylcholine administration to desaturation (SpO₂ < 90%) has been found as 8 min, 5 min, and 2.7 min in normal adults, moderately ill patients and obese patients respectively [6]. Recommended pre-oxygenation techniques include tidal volume ventilation with high FiO₂ for 3 min or 8 deep breaths with 100% FiO₂ [7].

**Aventilatory Mass Flow**

This is a physiological phenomenon. Metabolic O₂ consumption rate and CO₂ production rate in an adult patient are 250 mL/min and 200 mL/min respectively. Following denitrogenation of FRC, O₂ diffuses to the capillary blood with 250 mL/min rate. During apnea, CO₂ production does not change, but elimination of CO₂ is almost paused and diffusion slows down to only 10-20 mL/min [8,9]. As a result of this negative pressure gradient, a mass flow of gas from pharynx to alveoli occurs. CO₂ levels keep increasing. This causes a decrease in pH and respiratory acidosis. A high O₂ flow of > 15 L/min through nasal cannula washes dead space in lungs, thus restricts CO₂ increase. This also creates a "stent effect" via better gas washout. In several studies, patients were able to tolerate long apnea periods [9,10]. Average apnea duration changes between 5-45 minutes. CO₂ increase has been found between 1.1 to 3.4 mmHg/min during this application. CO₂ levels may increase up to 160 mmHg. Complications like seizures, cardiovascular collapse, and arrhythmias related to hypercapnia have not been reported.

The Canadian Airway Focus Group and Difficult Airway Society proposes this method in patients with anticipated difficult airway [4,11]. Additionally, Obstetric Anaesthetists’ Association also supports this method in obstetric patients with a possibility of failed airway management. Nasopharyngeal catheter, nasal cannula, face mask, Venturi mask, transtracheal endobronchial catheters, dual blade laryngoscopes and low flow oxygen or High Flow Nasal Cannula Oxygenation (HFNCO) systems are also usable for this method by applying high flow oxygen. However efficiency of oxygen flow applied by conventional methods are limited, because, these methods doesn’t provide enough warming and humidifying. This also causes a decrease in inspired oxygen concentration. Low flow systems have no effect on ventilation and CO₂ removal. Oxygen entrance port of nasopharyngeal airway permits oxygen insufflation. Nasopharyngeal catheter helps oxygen delivery to pharynx very effectively. If oxygen flow is between 1-8 L/min, this increases FiO₂ to 24-44%. But this method also removes humidity in mucosa, and may be disturbing for awake patients. That’s why high flow rates over 15 L/min is usually preferred in patients under general anesthesia.

Venturi mask is able to deliver 100% oxygen. This method increases FiO₂ up to 50%. Re-breathless masks has an oxygen reservoir and two valves. One of the valves is placed in exhalation port and the other is located between reservoir and face mask. This prevents air slip in. This increases FiO₂ up to 60-70% for flow rates over 15 L/min. Oxygenation is also possible through cricothyrotomy or a cannula inserted through endotracheal tube. Endotracheal catheters placed in right or left bronchi is another method of apneic oxygenation. Another technique is dual-use laryngoscope. Oxygen is applicable through a canal inside the blade. This makes insufflation of oxygen up to 15 L/min possible.

In recent years, high levels of humidified oxygen therapy through nasal cannula has been possible with advanced devices and it is possible to apply up to 70 L/min O₂ flow. Atelectasia risk following denitrogenation due to application of 100% oxygen is partially prevented by forming positive pharyngeal pressure. This method also makes application of positive pressure in low levels with nasal interface possible and provides controlled oxygen concentrations. Utilizing an oxygen/air blender, it is possible to obtain FiO₂ 0.21-1 with 60-70 L/min flow.

Gases are actively ventilated, humidified and inspired to the patient through a one-way circuit. High flow is 2-8 L/min for neonatal patients, 5-20 L/min for pediatric patients and 6-40 L/min for adults. Vapotherm, Optiflow, Aquinox, Precision Flow and Comfort-flow are some of brands manufacturing devices for high flow applications. Flexible delivery tubing system is able to provide a 70 L/min flow. A heating plate vapors water and delivers respiratory gas. This unit contains a passover humidifier, a high performance circuit and an Optiflow nasal cannula. This system delivers 44 mg H₂O/L gas heated to 37 °C and humidified, and is connectable to jack system directly. Nasal cannula may be in different sizes. Outer diameter of the cannula must be at least same with nostril diameter. This unit also has an adapter for use in connecting to tracheostomy of children weighing more than 15 kg.

AIRVO 2 is another mobile, ultrasonic, optiflow system. Pediatric nasal cannula contains a hydrocolloid sticky band which helps in fixing the unit. Aquinox TM high flow applicant system is able to deliver the gas in a flow rate of 35 L/min. Particles exiting from a Venturi heated and humidified shoes their effect in a closed chamber. Gas flow which contains humidified particles is delivered to the patient via a hollow tubing. Inner chamber forms particles as a humidifier and outer chamber delivers the gas to the patient. PARI Hydrate system uses pre-heated water system as a principle and is able to create air-flow. The advantage of this system is the ability to control heating according to desired humidity levels. There is no guide available created for high flow oxygen therapy application in pediatric or adult patient population. It is recommended to begin with flow levels of 8-10 fold of minute ventilation in some studies. Recommended flow rate is 8-12 L/min in infantile patients and 20-30 L/min in juveniles, starting with low flow and
This device also removes CO₂ limit oxygen dilution and reduce respiratory dead space. In airflow increases airway pressure by 0.5-1 cm H₂O due to positive airway pressure. Every 10 L/min increase in airflow decreases work in airway passage. This is used to prevent desaturation of obese patients are increased oxygen consumption, increased CO₂ production and increased alveolar ventilation. Metabolic rate is directly proportionate to body weight and amount of fat tissue. This reduces chest wall compliance.

Obese patients with BMI over 40 have a relative baseline hypoxemia. HFNCO reduces this dead space and increases alveolar ventilation. This reduces the respiratory workload. Corley, et al. [18] evaluated end-expiratory lung volumes with lung impedance tomography and found it higher in patients receiving low flow oxygen therapy with HFNCO. Several previous studies demonstrated that HFNCO produces 5 cm H₂O pressure on pharyngeal tissue when 35-40 L/min oxygen flow is applied. However, Piastro, et al. [19] did not observe any pressure changes in middle ear. This may suggest that HFNCO therapy is a good option for patients undergoing otological procedures.

Incidence of respiratory failure following extubation is around 10-20% and may require re-intubation [20]. Re-intubation due to respiratory failure is associated with increased Ventilatory Associated Pneumonia.

### Table 1: The comparison of HFNCO and NIV systems.

<table>
<thead>
<tr>
<th>HFNCO</th>
<th>NIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed flow and variable pressure levels</td>
<td>Variable flow for fixed pressure</td>
</tr>
<tr>
<td>Able to reduce dead space</td>
<td>Increases dead space</td>
</tr>
<tr>
<td>Does not effect tidal volume</td>
<td>May increase tidal volume</td>
</tr>
<tr>
<td>Reduces respiratory workload</td>
<td>More effective in reducing respiratory workload</td>
</tr>
<tr>
<td>Minimal gastric distention</td>
<td>Loss of pressure when mouth is opened</td>
</tr>
<tr>
<td>Pressure can be maintained</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2: Potential indications of HFNCO.**

<table>
<thead>
<tr>
<th>Preoxygenation before intubation</th>
<th>Moderate obstructive sleep apnea</th>
<th>Oxygenation following extubation</th>
<th>Sedation</th>
<th>Decrease in CO₂ levels</th>
<th>Acute COPD flare-ups</th>
<th>Postoperative hypoxemia</th>
</tr>
</thead>
</table>

Increasing the flow to the rate that is tolerable by the patient:

- 2-4 L/kg/min for 0-5 kg (up to 20 L/min)
- 2 L/kg/min for 5.1-12.5 kg (up to 25 L/min)
- 2 L/kg/min fow 12.6-35 kg
- Up to 70 L/min fow > 35 kg patients

**Noninvasive Ventilation (NIV) vs. HFNCO**

NIV connections increase anatomic dead space where as HFNCO reduces it. HFNCO does not actively cause increases in tidal volume, this only creates minor increases in end-expiratory airway pressure and reduces respiratory workload as effectively as NIV. But NIV is more effective in comorbid patients. A certain level of providing CPAP is possible with HFNCO therapy. This is flow-dependent and associated with mouth-opening. Features of HFNCO are summarized in Table 1 [15]. HFNCO system is potentially useful during awake fiberoptic intubation [16]. Conventional methods might be insufficient in preventing desaturation during awake intubation.

Miguel-Montanes, et al. [17] used non-rebreather mask and HFNCO during tracheal intubation in intensive care unit before and during the procedure. Lowest median SpO₂ during intubation for non-rebreathing masks was 94% while 100% for HFNCO. They demonstrated that HFNCO significantly reduces severe hypoxemia prevalence and increases patient safety. Potential areas of use for HFNCO are stated in Table 2. Causes of rapid desaturation of obese patients are increased oxygen consumption, increased CO₂ production and increased alveolar ventilation. Metabolic rate is directly proportionate to body weight and amount of fat tissue. This reduces chest wall compliance.
(VAP), mortality, prolonged stay in hospital and Intensive Care Unit (ICU). HFNCO is proven to be significantly increasing patient comfort and reducing the length of stay in hospital in patients undergoing lung resection.

Contraindications for this therapy include airway obstruction and facial trauma [21]. Airway obstruction restricts apneic oxygenation and this causes desaturation. Increase in CO\textsubscript{2} may also limit apneic oxygenation application. HFNCO therapy should be avoided if patient has risk of hypercapnia, increased intracranial pressure, hemodynamic instability or cardiac dysrhythmia. Complications are mucosal tissue damage, hypercarbia, acidosis and infection [10]. Hemodynamic changes occur due to sympathetic discharge following hypercarbia. Rising in venous return increases the left ventricular filling pressure, thus increasing cardiac output and possibility of life-threatening arrhythmias [22]. Apart from this, inappropriate use of HFNCO may compromise patient safety despite all its advantages in patients with respiratory failure.

Conclusions

Apneic oxygenation is increasingly used in ICU and operating rooms for difficult airway management by HFNCO systems. It is possible to deliver humidified and heated oxygen flow rates of up to 70 L/min. Apneic oxygenation requires a patent airway regardless of the technique used. Contraindications for this therapy include airway obstruction and facial trauma.

Acknowledgements

The authors state no conflict of interest.

References