Accepted Manuscript

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PII: S2210-8440(17)30137-5
DOI: 10.1016/j.tacc.2017.09.003
Reference: TACC 365

To appear in: Trends in Anaesthesia and Critical Care

Received Date: 29 May 2017
Revised Date: 3 September 2017
Accepted Date: 13 September 2017


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IS PREOXYGENATION STILL IMPORTANT? NEW CONCEPTS

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Key words: Preoxygenation, Desnitrogenation, Residual Functional Capacity, Oxygen Reserve Index, ORI, Transnasal Humidified Rapid-Insufflation Ventilatory Exchange, THRIVE, High Nasal Flow Oxygen Therapy, CPAP.
INTRODUCTION

Any anesthesiologist can confirm that after the induction of anesthesia, apnea time can usually be very short (as low as 1 to 3 minutes)\(^1\). However, this cannot be stated for a specific patient without a potential error which can entail very serious consequences. Difficulties regarding oxygenation through ventilation or intubation are difficult to predict\(^2, 3, 4, 5\). International guidelines for the management of the difficult airway stress the importance of anticipating these difficulties\(^6, 7, 8\). Before unanticipated difficulties and the possibility of a cannot intubate, cannot oxygenate situation, the most important thing is to have a predefined action plan in case difficult arises\(^9, 10\). Due to the impossibility of predicting these difficulties, international guidelines recommend optimal preoxygenation in all patients\(^11, 12\).

Preoxygenation describes the process of maximizing the amount of oxygen stored in the body before induction of anaesthesia, increasing the volume of oxygen available for respiration in pulmonary reserve and therefore safe apnoea time during intubation. Preoxygenation is essential to help prevent hypoxemia during emergency airway management.

The current review describes the physiologic basis and clinical benefits of preoxygenation; special considerations for preoxygenation in high-risk patient populations; monitoring technology and new techniques for preoxygenation are discussed.

PHYSIOLOGY OF THE PREOXYGENATION

Preoxygenation is primarily indicated in clinical scenarios such as rapid sequence intubation (full-stomach patients), prolonged intubation techniques such as double lumen tube intubation, bronchoscopic procedures with sleeping patients in apnea, septic or febrile patients, chronic obstructive pulmonary disease, obesity or pregnancy.
The term denitrogenation was first introduced by Hamilton and Eastwood in 1955 after proving that it was possible to eliminate 95% of nitrogen in a patient by breathing in a circular circuit with a 5 lpm fresh gas flow (FGF) for 2-3 minutes. Currently we prefer the term preoxygenation because the clinical objective is not to eliminate the existing N₂ but to replace it with oxygen therefore increasing the intrapulmonary oxygen reserve.

The main oxygen reserve is represented by functional residual capacity (FRC) which can reach a volume of up to 2500 ml by breathing 100% oxygen, which is around 8-10 times the oxygen consumption (Table 1, Figure 1: the data could differ between both as they are different studies). Actually, in the alveolar gas we can only reach a concentration of oxygen (FAO₂) of around 95% since the rest is occupied by carbon dioxide (CO₂) and water vapor (when breathing room air). Therefore, the objective to measure the adequacy of the preoxygenation technique is to obtain an expired fraction of O₂ (FEO₂) of over 90% (as we have just seen, hardly will we achieve a FEO₂ over 95%) and an expired concentration of nitrogen under 5% (Figure 2).

Table 1. Body O₂ Stores During Room Air and 100% O₂ Breathing.

<table>
<thead>
<tr>
<th>Store</th>
<th>Room Air</th>
<th>100% O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lungs</td>
<td>450 ml</td>
<td>3000 ml</td>
</tr>
<tr>
<td>Blood</td>
<td>850 ml</td>
<td>950 ml</td>
</tr>
<tr>
<td>Dissolved in tissue fluids</td>
<td>50 ml</td>
<td>100 ml</td>
</tr>
<tr>
<td>In myoglobin</td>
<td>200 ml</td>
<td>200 ml</td>
</tr>
<tr>
<td>Total</td>
<td>1550 ml</td>
<td>4250 ml</td>
</tr>
</tbody>
</table>

Figure 1. Variation in the volume of O2 stored in the functional residual capacity (△), blood (▲), tissue (○), and whole body (●) with the duration of preoxygenation. From Campbell and Beatty. 19

Figure 2. Comparison of mean end-tidal oxygen and nitrogen concentrations obtained at 30-s intervals during 5-min periods of spontaneous tidal volume oxygenation using...
the circle absorber and NasOral systems in 20 volunteers, both techniques seem to agree very well. Data shown as mean +/- SD. From Nimmagadda et al.\textsuperscript{20}

If we consider oxygen consumption constant, approximately around 250 ml in young adults, we can calculate that a healthy patient has an oxygen reserve for around 9-10 minutes when breathing 100% oxygen. On the other hand, this reserve drops to less than a minute when breathing room air (taking into account a 2500 ml FRC and a concentration of Hb of 14.0 g/dl). However, healthy patients under normal circumstances, present shorter safe apnea times (when saturation remains over 90%), of around 6.9 minutes after breathing 100% O\textsubscript{2}, 5 minutes after 80% oxygen, 3.5 minutes after 60% oxygen and under one minute with room air\textsuperscript{21} (Figure 3).

Figure 3. Arterial oxyhemoglobin saturation (SaO\textsubscript{2}) versus time of apnea in an obese adult, a 10-kg child with low functional residual capacity and high ventilation, and a moderately ill adult compared with a healthy adult. FAO\textsubscript{2} indicates fractional alveolar oxygen concentration; VE, expired volume. Published from Benumof et al.\textsuperscript{22}
Yet, it is possible to increase these safe apnea times, by means of correct preoxygenation, through a physiological phenomenon known as apneic ventilation or oxygenation, first described by Bartlett in 1959, using a pressure limited gas flow to the lungs of up to 20 cmH₂O, created by the difference between excreted CO₂ and absorbed CO₂. This phenomenon sets the basis for the utilization of continuous positive airway pressure techniques (CPAP, BiPAP, THRIVE) as to prolong the safety interval by means of this “apneic diffusion oxygenation”. We know that in a patient with an open airway, this apneic diffusion process can keep saturation over 90% for up to 100 minutes. This apnea time is longer with higher FRC and with inspired fractions of O₂ (F_iO₂) over 0.9. Nevertheless, it has been subject of much discussion since the degree of CO₂ clearance is similar to that of an obstructed patient, with increases of pCO₂ between 0.35 and 0.45 kPa/min, this being the main limiting factor for the clinical use of this technique.

As we have previously stated, the key to perform optimal preoxygenation is alveolar nitrogen clearance. This process follows an exponential curve, determined by the time constant, so that theoretically after 4-5 time constants we could increase O₂ up to 98% of FRC. This time constant is influenced by the FRC and by alveolar ventilation. FRC usually remains constant for the same patient. For example, if we consider a 2.5 L FRC, the time constant will be 26 seconds when alveolar ventilation (=FGF) is 4 lpm and 13 seconds when increased to 8 lpm. This shows how hyperventilation can reduce preoxygenation times to increase pulmonary oxygen stores, therefore supporting the use of vital capacity inspirations instead of tidal volume ventilation.

We have to consider too that in anesthesia we usually use semi-closed circuits and thus attention should be paid to control re-inhalation of nitrogen to avoid the reduction of F_iO₂ in the gas flow. Sometimes, increasing FGF is enough to avoid this re-inhalation (10-12 lpm). The main objective is to achieve maximum preoxygenation (efficacy) which can be easily measured with the available monitors.
PREOXYGENATION TECHNIQUES

Initially, all preoxygenation techniques require a spontaneously breathing patient with FIO\(_2\) 100%, in a perfectly pure O\(_2\)-purged circuit, a fresh gas flow that will prevent re-inhalation and a perfectly sealed facemask with no leaks nor imperfections\(^{29}\), since we can have a 20% dilution of O\(_2\) when the facemask is not perfectly sealed and up to 40% when we only keep it close to the face \(^{30}\). During preoxygenation the patient is usually lying down (relative decrease of FRC), yet the oxygen reserve has been shown to increase with a 25º elevation of the head, especially recommended for obese patients.

Different techniques of preoxygenation have been described, sometimes classified according to the time needed for their execution (Table 2).

Table 2. Techniques of preoxygenation.

<table>
<thead>
<tr>
<th>Slow techniques (3-5 minutes)</th>
<th>Fast techniques (30-60 seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume breathing</td>
<td>Single tidal capacity breath</td>
</tr>
<tr>
<td>One vital capacity breath followed by tidal volume breathing</td>
<td>Four deep breaths (4 inspiratory capacity breaths)</td>
</tr>
<tr>
<td>Fast techniques (30-60 seconds)</td>
<td>Eight deep breaths (8 inspiratory capacity breaths)</td>
</tr>
<tr>
<td>Extended deep breathing (12–16 inspiratory capacity breaths)</td>
<td></td>
</tr>
</tbody>
</table>

Slow techniques usually correspond to tidal volume breathing for 3-5 minutes \(^{32}\). Fast techniques with vital capacity or deep breathing for 30 – 60 seconds (4-8 breaths) have certain advantages in emergency scenarios or during rapid sequence intubation, although they need cooperative patients and high gas flows\(^{28}\). The 8 deep breaths...
technique prior forced expiration is preferably used over the 4 breaths technique (30 seconds)\textsuperscript{32,33,34}, with similar results as those from slow tidal volume techniques (table 3).

Table 3. Comparison of different techniques in normal adults. (Modified of Tanoubi et al. Can J Anaesth 2009; 56: 449-66\textsuperscript{40})

<table>
<thead>
<tr>
<th>Clinical Study</th>
<th>Endpoint</th>
<th>Preoxygenation technique</th>
<th>Best technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TVB 3min</td>
<td>4DB30sec</td>
</tr>
<tr>
<td>Baraka\textsuperscript{33}</td>
<td>DAWD (min)</td>
<td>3.73 ± 0.76</td>
<td>2.78 ± 0.39</td>
</tr>
<tr>
<td>Pandit\textsuperscript{34}</td>
<td>FEO\textsubscript{2} (%)</td>
<td>92 ± 1</td>
<td>83 ± 2</td>
</tr>
<tr>
<td></td>
<td>Oxygen uptake(L)</td>
<td>2.23 ± 0.95</td>
<td>1.67 ± 0.45</td>
</tr>
<tr>
<td>Nimmagadda\textsuperscript{35}</td>
<td>FEO\textsubscript{2} (%)</td>
<td>88 ± 5</td>
<td>80 ± 5</td>
</tr>
</tbody>
</table>

TVB = tidal volume breathing for 3 min
4 DB 30 sec = four deep breaths in 30 sec
8 DB 60 sec = eight deep breaths in 60 sec
DAWD = duration of apnea without desaturation
FEO\textsubscript{2} = expired fraction of oxygen

In 1955 Hamilton proposed a preoxygenation technique with tidal volume in spontaneous breathing for 3 minutes which is currently still in force. After the first minute under FIO\textsubscript{2}=1 breathing we achieve the best saturation; but it is necessary to have at least three minutes of breathing to prolong the apnea time, when anesthesia induction is accomplished \textsuperscript{36, 37}.

Vital capacity techniques have been used with emergency patients when there is no time for the standard technique \textsuperscript{38}. We need to use an oxygen flow higher that the
patient’s peak inspiratory flow with an appropriate reservoir bag. The technique with one vital capacity breath prior forced expiration has proven appropriate for preoxygenation in emergent patients in rapid sequence intubation.  

There are certain groups of patients which will benefit from specific techniques of preoxygenation since they present significantly reduced apnea times (Table 4). Moreover, they have a series of particularities which are worth taking into account.


<table>
<thead>
<tr>
<th></th>
<th>FRC (1)</th>
<th>FEO₂</th>
<th>FEO₂ Sat=90%</th>
<th>O₂ consumption (2)</th>
<th>DAWD (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No preoxygenation</td>
<td>2500</td>
<td>16</td>
<td>10</td>
<td>250</td>
<td>0.6</td>
</tr>
<tr>
<td>Normal preoxygenation</td>
<td>2500</td>
<td>90</td>
<td>10</td>
<td>250</td>
<td>8.0</td>
</tr>
<tr>
<td>Poor preoxygenation</td>
<td>2500</td>
<td>60</td>
<td>10</td>
<td>250</td>
<td>5.0</td>
</tr>
<tr>
<td>Obese</td>
<td>1250</td>
<td>90</td>
<td>10</td>
<td>350</td>
<td>2.9</td>
</tr>
<tr>
<td>Obese head-up</td>
<td>1500</td>
<td>90</td>
<td>10</td>
<td>350</td>
<td>3.4</td>
</tr>
<tr>
<td>Pregnant</td>
<td>1000</td>
<td>90</td>
<td>10</td>
<td>400</td>
<td>2.0</td>
</tr>
<tr>
<td>Elderly</td>
<td>2250</td>
<td>90</td>
<td>10</td>
<td>200</td>
<td>9.0</td>
</tr>
</tbody>
</table>

FRC= functional residual capacity  
DAWD= duration apnea without desaturation  
FEO₂= expired fraction of oxygen  
SpO₂= oxygen saturation  
Value: (1)= mL; (2)= mL.min⁻¹; (3)= min

Obese patients have a significantly reduced vital capacity, which becomes more important when lying down due to the diaphragmatic compression of a large abdomen. Furthermore, they present increased intrapulmonary shunt and oxygen consumption. This leads to shorter alveolar denitrogenation times but to a reduced duration of safe
Apnea. The 8 deep breaths and tidal ventilation methods are also safe in obese patients. The mean time of apnea after correct preoxygenation in obese patients is severely shorter, of around 2.7 minutes in comparison with 6 minutes in normal patients. This could be increased in around 50 seconds if we perform the technique with a 25° head-up position. The use of CPAP ventilation can improve oxygenation, due to an enhanced ventilation-perfusion, and also prolong the non-hypoxic apnea duration.

Pregnant patients also entail an important challenge due to the reduction of FRC and the increase of alveolar ventilation and oxygen consumption. The oxygen flow needs to be increased to at least 10 lpm. Preoxygenation times are shorter as well as safe apnea times which drop to 173 seconds in pregnant women (243 in non-pregnant women). As with obese patients, the preferred technique is that of 8 vital capacity breaths and tidal volume breathing. Unlike obese patients, the position does not affect preoxygenation.

Elderly patients benefit from tidal volume preoxygenation due to their restrictive patient condition and reduced FRC, which is not compensated by their low oxygen consumption and thus safe apnea times are significantly shorter. Like elderly patients, patients with pulmonary disease require longer preoxygenation times, which can be up to 5 minutes with the tidal volume technique.

On the other hand, pediatric patients present higher oxygen consumption, which together with their reduced FRC entail significantly shorter safe apnea times. Therefore, after 2 minutes of tidal volume preoxygenation the maximum benefit for a safe apnea time of up to 5 minutes is achieved in comparison with 0.47 minutes with no preoxygenation.

**PREOXYGENATION MONITORING**
As previously discussed the standard practice of preoxygenating with 100% oxygen before the induction of general anaesthesia is strongly recommended because it delays the onset of arterial hemoglobin desaturation during a potential prolonged apnea\textsuperscript{1,53}. The oxygen loading process during preoxygenation involves factors related to alveolar, arterial, venous and tissue compartments and those that interact with the delivered fraction of inspired oxygen\textsuperscript{40}. Because most of the oxygen is stored in the lungs as a function of FRC, the primary goal is to maximize the alveolar fraction of oxygen, which depends on the effective FiO\textsubscript{2} delivered\textsuperscript{54}.

In an adult subject with a normal functional residual capacity and oxygen consumption (VO\textsubscript{2}), an end-tidal oxygen > 90% implies that the lungs contain >2000 mL of O\textsubscript{2}, which is 8 to 10 times the VO\textsubscript{2}\textsuperscript{16,1}. Because of the obligatory presence of carbon dioxide and water vapor in the alveolar gas, an FEO\textsubscript{2}>94% cannot be easily achieved\textsuperscript{55}.

The two main surveillance techniques for monitoring preoxygenation are pulse oximetry and O\textsubscript{2} telexpiratory fraction analysis. The measurement of oxygen saturation (SpO\textsubscript{2}) does not make it possible to correctly evaluate the effectiveness of preoxygenation\textsuperscript{54}.

The principle is to reduce the risk of hypoxia by providing a reservoir of 95% oxygen (assuming an obligatory 5% alveolar carbon dioxide) in the patient's lungs for planned or unplanned periods of apnoea during the induction period\textsuperscript{18}. When most of the nitrogen in the lung is replaced by oxygen, the expired oxygen increases to slightly greater than 90%, satisfying the recommendation for adequate preoxygenation\textsuperscript{54}, but it does not allow to appreciate the tissue reserves of oxygen. Monitoring of FEO\textsubscript{2} is recommended during preoxygenation (Grade E)\textsuperscript{53}.

\textbf{Preoxygenation failure}
Inadequate preoxygenation, defined as a $\text{FEO}_2<90\%$ after three minutes of tidal volume breathing, is seen frequently in practice (56\% in a sample of 1050 patients). The effective $\text{FiO}_2$ delivered was observed to be lower in patients with a $\text{FEO}_2<90\%$. Risk factors for inadequate preoxygenation were determined to be bearded male, beardless male, ASA physical status classification system $>1$, lack of teeth, and age $>55$ years. These predictive factors overlap with those previously associated with difficult mask ventilation.

While $\text{SpO}_2$ measurement is not informative regarding the quality of preoxygenation maneuvers, it is essential to identify oxygenation problems. The $\text{FEO}_2$ depends on the tidal volume; small tidal volumes increase the difference between $\text{FEO}_2$ and $\text{FAO}_2$, leading to overestimation of $\text{FAO}_2$. The $\text{CO}_2$ wave shape is informative regarding the quality of the ventilation and the tightness of the circuit; a $\text{FEO}_2<90\%$ indicates incomplete denitrogenation at the FRC level.

Even if the mechanisms that cause incomplete denitrogenation are not identified, this monitoring method has utility in routine practice. If the $\text{FEO}_2$ cannot be increased above 90\%, pressure support ventilation may be proposed to improve preoxygenation quality. In emergency medicine, the monitoring of preoxygenation is typically based on $\text{SpO}_2$ measurement and preoxygenation duration, as the $\text{FEO}_2$ is not usually available.

**New monitoring method for preoxygenation**

The primary reason of the preoxygenation is that filling the functional residual capacity of the lungs provides several minutes’ worth of oxygen “reserve” in case of airway compromise. Once desaturation starts during an airway crisis, it typically progresses rapidly to potentially lethal levels.
Pulse oximetry provides continuous, noninvasive assessment of arterial oxygen saturation and is a sensitive detector of hypoxemia\textsuperscript{57} and major hypoxic events\textsuperscript{58}. However, oxygen supplementation delays detection of hypoventilation by pulse oximetry because oxyhemoglobin saturation remains 100\% over a wide range of oxygen partial pressures exceeding about 80 mmHg\textsuperscript{59}. For this reason, it is difficult to predict when desaturation will start in patients with SatO\textsubscript{2} 100\% as the desaturation will start when pO\textsubscript{2} decrease below 80 mmHg and we do not know what pO\textsubscript{2} is for these patients.

**IMAGE 1.**

The ORI (Oxygen Reserve Index) is a novel pulse oximeter-based non-dimensional index that ranges from 1 to 0 as partial pressure of arterial oxygen (PaO\textsubscript{2}) decreases from about 200 to 80 mmHg. The ORI enables detection of changes in PaO\textsubscript{2} relative to the changes in SvO\textsubscript{2}, combining the Fick principle with the absorption properties of both arterial and venous hemoglobin wavelengths\textsuperscript{60}. Specifically, as PaO\textsubscript{2} increases beyond 100 mmHg, SvO\textsubscript{2} continues to increase, even though SaO\textsubscript{2} has effectively saturated at 100\%. This modest increase in SvO\textsubscript{2} above its normal value of approximately 75\% will eventually stop as PaO\textsubscript{2} reaches significantly higher values (i.e., more than 200 mmHg).

One must understand that the venous saturation will depend not only on the oxygen supply via the lungs but also by other factors including oxygen consumption, cardiac output, blood pH, partial pressure of carbon dioxide, temperature, the amount of perfusion (venous pulsation), and the presence of abnormal hemoglobins\textsuperscript{60}. In particular, the cardiac output is an important “confounder” that may need other treatment than to keep the lung open.
ORI is an earlier warning system that can indicate when patients have been adequately preoxygenated and might have utility as an adjunct monitor of hypoventilation in patients who are on supplemental oxygen and whose PaO$_2$ is increased$^{61}$. Decreases in ORI to near 0.24 may provide an advance indication of falling PaO$_2$ when SpO$_2$ is still $>98\%$ and above the PaO$_2$ level at which SaO$_2$ declines rapidly$^{62}$. So far there are very few studies on ORI, so further studies are needed to assess the role of ORI in preoxygenation monitoring.

**NEW PEROXGENATION TECHNIQUES.**

**THRIVE.**

THRIVE (transnasal humidified rapid-insufflation ventilatory exchange), describes a technique that maintains oxygen saturation for significant periods of time after commencement of apnea in surgical patients and reduces the rise of CO$_2$ over time$^{63}$. This suggests that utilizing high-flow nasal oxygen at almost 60 L per minute during the apneic period allows apneic oxygenation (maintaining oxygen saturations) and apneic ventilation (reducing the rise of CO$_2$). This is in contrast to low-flow nasal cannula techniques in which classic apneic oxygenation improves oxygenation without affecting ventilation$^{64}$.

The HFNC (high-flow nasal cannula) system includes cannula, turbine, and a respiratory gas humidifier. It generates 2-60 L/min of flow with oxygen concentration of 21-100%, capable of matching or exceeding the patient's peak inspiratory flow, preventing room air entrainment. Low-flow devices, nasal cannula, can supply FiO$_2$ of 0.36 and also do not match the peak inspiratory flow rates of the patient and ambient air is entrained to dilute the inspired oxygen$^{65}$. 

A quiet motor draws in room air and oxygen through a filter. Blended breathing gas is passed through a water chamber to be humidified and breathing tube heated to minimize condensation. Heated pass over humidifier atomizes the water molecule, unlike the nebulizers which produce water droplets which cause infection. Humidified air with atomized water molecule is passed through soft nasal cannula of different sizes while the whole system is integrated into a mobile stand for convenient bedside positioning\(^65\).

HFNC offers several benefits in management of respiratory failure during preoxygenation and also throughout the process of endotracheal intubation itself. HFNC offers continuous delivery of high FiO\(_2\), which can help gas exchange and promote apneic oxygenation but also could provide a low PEEP effect on alveolar recruitment and upper-airway splinting\(^66\). As opposed to other oxygen-delivery methods strictly limited to the preoxygenation process but not maintainable throughout the process of intubation itself (non-rebreathing mask, face mask noninvasive ventilation, bag-valve-mask), HFNC use can be extended through the whole process and all stages of endotracheal intubation\(^67\).

**IMAGE 2.**

In spontaneously breathing patients, multiple physiological benefits of HFNO have been described, which include an increased FiO\(_2\), possible generation of low positive airway pressure, improved respiratory mechanics and reduced upper airway resistance\(^68, 69, 70, 71\). To date, these clinical benefits during spontaneous ventilation have been limited to awake patients (respiratory supportive care, preoperative preoxygenation, postoperative support)\(^68,69,72\), sedated patients (procedural bronchoscopy or awake fibreoptic intubation)\(^71,73\) or asleep patients with obstructive sleep apnoea\(^74\), and recently has been described the application of HFNC to spontaneously breathing patients during general anaesthesia\(^75\).
The use of nasal cannula adapted to nare size to deliver heated and humidified gas at high flow rate has been associated with improvement in washout of nasopharyngeal dead space. It creates passive pharyngeal pressure to reduce the work of breathing, which positions the device in the middle between classical oxygen delivery options, i.e., facemask and continuous positive airway pressure. The end expiratory pressure is determined not only via flow but also by the ratio of the prong/nostril fit and whether the mouth is closed. It supports the inspiratory effort when patient flow is limited.

It has been shown to increase oxygen saturation, arterial oxygen partial pressure, prevent hypercarbia, and decrease the frequency of breathing in emergency department and intensive care settings, to treat acute respiratory failure, prevent postoperative atelectasis, alleviate dyspnea in acute heart failure and increase the apneic window during tracheal intubation.

Otherwise, a recent study of Ang et al. on twenty-one healthy volunteers aged 23-59 years, demonstrated that the Optiflow system increased FEO2 rapidly, however they detected a wide variability in the extent of denitrogenation suggesting that it might not be a reliable alternative to face mask ventilation in preoxygenating patients. Furthermore, transnasal humidified rapid-insufflation ventilatory exchange significantly prolongs the safe apnoeic oxygenation time in infants and children with healthy lungs in comparison to infants and children who did not receive THRIVE, but the rate of increase per minute in transcutaneous CO2 during apnoea, however, was similar in both groups; hence, THRIVE maybe did not prevent the potential side-effects originating from hypercarbia-related adverse events.

THRIVE remains a new technique which has not been fully characterized, but holds great promise. Until now, all ventilation strategies in the operating room have depended on some form of tidal breathing, whether spontaneous, mechanically supported, or controlled. THRIVE potentially represents an easily implemented way to achieve oxygenation and ventilation without an invasive device or tidal respiratory movements.
but since there are conflicting studies, it is necessary for further research to clarify its role in the preoxygenation and CO₂ clearance.

CPAP (Continuous Positive Airway Pressure)

The development of atelectasis is a consistent finding with the use of 100% oxygen for pre-oxygenation before induction of anaesthesia. The use of lower fractional concentration of inspired oxygen may increase this risk of hypoxaemia, especially when difficulty in airway management and/or ventilation is encountered. Some investigators have found that during routine induction of general anaesthesia, pre-oxygenation with 80% oxygen caused minimal atelectasis, but the time duration before desaturation occurred was significantly shortened compared to a situation when 100% oxygen was inhaled.

Continuous Positive Airway Pressure increases FRC to or above a lung volume greater than closing capacity (CC), thereby restoring a normal FRC to CC relationship, so that no airways are closed at any time during the tidal respiration. Application of CPAP during induction of anaesthesia increases the duration of non-hypoxic apnoea by preventing atelectasis formation, increasing oxygen stores, and decreasing intrapulmonary shunt.

The application of positive airway pressure during pre-oxygenation and induction of anaesthesia may have advantages especially in those patients in whom difficulty in airway management is anticipated, those who are more at risk of desaturation such as morbidly obese patients and when assisted ventilation is not applied such as during rapid sequence induction. The application of CPAP can have potentially deleterious effects on the cardiovascular system but through the use of a pressure of 5 cmH₂O during pre-oxygenation, it is unlikely to produce any significant effects on the heart rate and blood pressure.

CONCLUSIONS
Due to the impossibility of predicting ventilation or intubation difficulties, international guidelines recommend optimal preoxygenation in all patients, so it is still very important. The two main surveillance techniques for monitoring preoxygenation are SpO₂ and FEO₂. ORI is a novel pulse oximeter-based nondimensional index; decreases in ORI to near 0.24 may provide advance indication of falling PaO₂ when SpO₂ is still >98% and above the PaO₂ level at which SaO₂ declines rapidly.

THRIVE describes a technique that maintains oxygen saturation for significant periods of time after commencement of apnea in surgical patients and reduces the rise of CO₂ over time. Potentially it represents an easily implemented way to achieve oxygenation and ventilation without an invasive device or tidal respiratory movements, but since there are conflicting studies, it is necessary for further research to clarify its role in the preoxygenation and CO₂ clearance.

The use of CPAP about 5 cmH₂O during preoxygenation allows use of FiO₂ 100 % preventing atelectasis formation, and prolongs apnea time, with minimal deleterious effects on the cardiovascular system.
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Highlights

- Due to the impossibility of predicting ventilation or intubation difficulties, international guidelines recommend optimal preoxygenation in all patients, so it is still important.

- The Oxygen Reserve Index (ORI) is a novel pulse oximeter-based nondimensional index that alerts in advance from a desaturation.

- THRIVE (transnasal humidified rapid-insufflation ventilatory exchange) could maintain oxygen saturation for significant periods of time after commencement of apnea, but it is necessary for further research to clarify its role in the preoxygenation and CO2 clearance.