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Oxygenation before anesthesia (preoxygenation) in adults

BY ISSAM TANOUBI, MD

Preoxygenation has been a recognized technique since 1955. Its purpose is to increase the oxygen reserves in the body and thus prolong the safe period of apnea between induction of anesthesia and the moment the airway is secured. This extra time can be life-saving when ventilation and intubation are impossible – "cannot ventilate, cannot intubate" – or difficult. The first part of this update reviews the physiopathological mechanisms responsible for tissue oxygenation and the importance of preoxygenation. The second part reviews the effectiveness of preoxygenation in different settings, as well as the various techniques that allow optimal effectiveness.

WHY PREOXYGENATE?

Oxygen reserves in the body[2]

During the apneic period following induction of anesthesia, tissue oxygenation proceeds at the expense of the body's oxygen reserves. These reserves are quantitatively small and are located in 3 compartments: the lungs, the plasma, and the red cells (Table 1). Added to these three main reserve compartments is the oxygen, non-mobilizable during apnea, which is present in the interstitial space and that stored in myoglobin. Practically speaking, preoxygenation increases the reserves of the body, mainly through the increase in oxygen concentration in the functional residual capacity (FRC). Replacement of nitrogen by oxygen during preoxygenation takes place rapidly at first, but slows down as the process continues.[3]

Utilization of oxygen reserves

The oxygen consumption of young, awake subjects at rest amounts to approximately 300 mL/min, but decreases by about 15% in the elderly.[2] Under anaesthesia,[3] it can decrease by half. The duration of apnea without desaturation is determined by the initial amount of oxygen stored, tissue availability, and rate of oxygen consumption. If the subject has breathed ambient air, these reserves allow, at best, 3 minutes of apnea with no important decrease in O_2 carried; if the subject has been properly preoxygenated, this time can be doubled. The duration of apnea without desaturation is reduced when oxygen reserves are diminished (eg, by obesity, pregnancy, anemia, high pCO_2) or when there is high oxygen consumption (fever, pregnancy).[4]

WHO SHOULD BE PREOXYGENATED?

Preoxygenation is necessary during induction of anesthesia if there is a potential risk of desaturation before airway patency is secured or when there are anticipated problems with oxygenation. Examples:

- rapid sequence induction
- anticipated difficult mask ventilation
- presumed difficult intubation
- anatomical malformations or specific technical issues (eg, double lumen tracheal tube for thoracic surgery)
- obesity, pregnancy, bowel obstruction, ascites (when intubation and ventilation difficulties, respiratory dysfunction with a decrease in FRC, and risk of regurgitation are all present)
- increased oxygen consumption (febrile patients or pregnant women).[6]

Other than these high-risk situations, oxygen reserves are theoretically sufficient to cover the duration of apnea following induction, before ventilation with a face mask, or before the upper airway is patent and secure.[4] Without preoxygenation, manual ventilation with 100%

TABLE 1: Oxygen reserves in the body, with room air and after oxygenation

Compartment	Factors	With room air (mL)	With O_2 100% (mL)
Lung	F_{AO2} - FRC	630	2850
Plasma	p_{aO2} - DF - PV	7	45
Red blood cells	Hb - TGV - S_{aO2}	788	805
Myoglobin (stable and non-mobilizable)		200	200
Interstitial space (non-mobilizable)		25	160
TOTAL MOBILIZABLE RESERVES		**1425**	**3699**

F_{AO2} = Alveolar fraction of oxygen, rises to 95% with pure oxygen preoxygenation (due to carbon dioxide which is 5% of alveolar gas); FRC = Functional residual capacity, 2,500 to 3,000 mL for medium-sized adults; p_{aO2} = partial pressure of oxygen in arterial blood, 80 mm Hg with room air and up to 500 mm Hg with pure oxygen; DF = percentage of dissolved form (0.3%); PV = plasma volume (3L); Hb = hemoglobin concentration in blood; TGV = total globular volume (5L); S_{aO2} = oxygen arterial saturation = 98% with room air and 100% with pure oxygen.

oxygen for one minute before intubation is as effective as 3 minutes of preoxygenation in preventing episodes of desaturation at induction of anaesthesia.[7]

Should we preoxygenate systematically?

Preoxygenation might seem useless or undesirable in healthy patients because:

- the risk of respiratory incident during induction is relatively low
- it prolongs induction by 1 to 5 min
- it increases alveolar collapse at induction
- the firm application of a face mask might cause anxiety in some patients.

Conversely, several authors have recommended preoxygenation before every general anesthetic, for the following reasons:

- arterial desaturation is observed at induction in 15% to 60% of non-preoxygenated healthy patients[8]
- it is difficult to accurately predict difficulties with mask ventilation and tracheal intubation[9]
- if laryngospasm or vomiting occurs, the risks of severe hypoxemia are increased.

HOW TO PREOXYGENATE?

Preoxygenation techniques

An expired fraction of oxygen (F_{EO2}) > 90% is considered adequate for the induction of general anesthesia. The rate of denitrogenation depends on the inspired fraction of oxygen, on the inspired volume, and on the respiratory rate. The different variations of these last two factors are the origin of two common preoxygenation techniques:

- *A slow technique*: tidal volume breathing for 2-5 min (TVB 2-5 min). For patients breathing through a circuit supplied with pure oxygen at a fresh gas flow of 4 L/min, lung denitrogenation is 95% complete after 3 minutes. In clinical practice, most patients are adequately preoxygenated after 3 minutes of tidal volume breathing with an inspired fraction of oxygen (F_{IO2}) of 100%.[10]
- *Fast techniques*: 4 to 8 deep vital capacity breaths at F_{IO2} = 100% in 30 to 60 seconds (4-8 DB 30-60 s). The alveolar oxygen fraction increases even more rapidly, since ventilation is high. This is the basis of fast preoxygenation methods.[11]

Comparative efficiency of the techniques (Table 2)

Among the first studies comparing the two techniques, the article by Gold et al[12] measured oxygen saturation and the oxygen partial pressure in arterial blood (p_{aO2}) after preoxygenation either with TVB 3 min, or 4 DB 30 sec. There was no significant difference in the measures obtained between the two techniques. The authors thus concluded that both techniques were equivalent. However, neither the F_{EO2} nor the duration of apnea were measured.

Subsequently, the fast 4 DB 30 sec technique proved less effective than the slow method.[13] This could be due to three phenomena: first, there is nitrogen rebreathing[14-16] when minute ventilation with 4 DB in 30 sec exceeds fresh gas flow. Second, the short duration of this type of preoxygenation does not allow plasma or tissue transfer, which are slow and linear.[10] Finally, this technique is very dependent on patient understanding and cooperation, which explains its success in healthy volunteers and failure in elderly subjects.[15]

Whereas the 4 DB 30 sec technique is more or less effective, the 8 DB method has proven equivalent to slow techniques in several studies.[10,17,18] This technique also allows the opening of collapsed alveoli by deep inspirations and a better oxygenation of the FRC. The effectiveness of this technique is proven mainly when associated with a high fresh gas flow.[19]

The comparison of preoxygenation regimes often reveals variable and sometimes contradictory results. This might be because of methodological differences, as well as differences in the populations studied, anesthetic circuits, fresh gas flows, and the choice of primary outcome measurement. For instance, Nimmagadda et al[17] demonstrated that the 8 DB method becomes as effective as the TVB 3 min, only if the fresh gas flow is greater than 10 L/min. The measured parameter is thus important. In this respect, time to desaturation reveals more about the effectiveness of a technique than surrogate measures such as p_{aO2}.

Maximal expiration before the slow method (TVB 3 min) allows the denitrogenation of the functional residual capacity that results in a reduction of the time necessary for slow preoxygenation: the F_{EO2} is higher (>90%) and achieved more rapidly (2 instead of 3 min).[20]

PREOXYGENATION IN OBESE PATIENTS

Respiratory repercussions of obesity

After 3 to 4 minutes of classical preoxygenation, the duration of apnea allowing the maintenance of S_{aO2} above 90% is 3 min in obese patients compared with almost 10 minutes in healthy subjects. The time needed for saturation to rise to 96% is also prolonged: 37 sec in obese patients compared with 22 sec in healthy subjects.[23] Several elements account for the increased risk of hypoxemia during induction of obese patients:

- intubation is delayed because it is more difficult[9]
- duration of apnea is reduced because of a high oxygen consumption, decreased rib cage compliance, increased lung resistance, and most importantly, a reduction in FRC

TABLE 2: Comparison of preoxygenation techniques in healthy adults

Study	Population	Compared techniques	Interventions	Results
Gold, 1981[12]	n = 22 ASA I – II	TVB 5 min 4 DB	Measurement of S_{aO2} and C_{aO2}	TVB 5 min = 4 DB
Gambee, 1987[13]	n = 12 ASA I non smokers	TVB 3 min 4 DB	Measurement of apnea time until desaturation	TVB 3 min > 4DB
McCrory, 1990[14]	n = 20 Healthy volunteers	TVB 3 min 4 DB	Anti-rebreathing valve	TVB 3 min = 4DB
Rooney, 1994[21]	Healthy volunteers	TVB 3 min 2 to 8 DB	Forced expiration before TVB 3 min	2 to 3 DB < TVB 3 min 4 to 5 DB = TVB 3 min 6 to 8 DB > TVB 3 min
Baraka, 1999[10]	n = 56 Cardiac surgery	TVB 3 min 4 DB 8 DB	Fresh gas 5 or 10 L/min	TVB 3 min > 4DB TVB 3 min = 8DB 8DB > 4DB
Baraka, 2000[22]	n = 10 ASA I and II	TVB 3 min 1 DB	1 DB realized following a forced expiration Measure of p_{aO2}	TVB 3 min = 1 DB
Nimmagadda, 2001[17]	n = 10 Healthy volunteers	TVB 3 min 4 DB 8 DB	Variable fresh gas flow Duration of DB > 1 min	TVB 3min > 4DB TVB 1,5 to 2 min = 4 DB 8 DB > 4DB 8 DB = TVB 3 min only if fresh gas flow > 10 L/min and 8 DB in > 1 min
Baraka, 2003[21]	n = 23 Healthy volunteers	TVB 3 min TVB 3 min after forced expiration	Measurement of F_{EO2}	Maximum F_{EO2} reached in 2 instead of 3 min. with forced expiration
Pandit, 2003[18]	n = 60 Healthy volunteers	TVB 3 min 4 DB 8 DB	Physiological study of preoxygenation	TVB 3 min > 4DB 8 DB > 4DB TVB 3 min = 8 DB
Gagnon, 2006[22]	n = 20 Healthy volunteers	TVB 3 min 4 DB	Provoked leak around the face mask	Both techniques equally ineffective with leak

ASA = classification of the American Society of Anesthesiologists; TVB = tidal volume breathing; DB = deep breaths; S_{aO2} = oxygen saturation; C_{aO2} = arterial oxygen content; F_{EO2} = expired fraction of oxygen.

- vital capacity and expiratory reserve volume are decreased, with an increased closing volume (exceeding FRC)[24]
- downward diaphragmatic movements are limited
- greater atelectasis and increase in closing volume result in ventilation/perfusion mismatch.[25]

All these anomalies are exaggerated during anesthesia. Moreover, diaphragmatic and upper airway tone decreases. Jense et al[23] found a linear relationship between the time to desaturation and the extent of obesity after 5 min of preoxygenation, in patients with the same initial p_{aO2}. The main cause was the FRC decrease, which was as high as 1.3 L. In some cases the delay before desaturation was < 100 seconds,[26] which, in practice, means a single laryngoscopy. There is no correlation between the initial p_{aO2} level before induction and time to desaturation.

Effectiveness of preoxygenation techniques

Fast preoxygenation techniques were tested on morbidly obese patients (Table 3), revealing good results for P_{EO2} and p_{aO2},[16,27] but the slow technique offers a better apnea time without desaturation. The advantage of using 4 DB 30 sec could be the correction of hypercapnia associated with premedication.[16] The 8 DB technique is as effective as the TVB 3 min in obese patients with regards to F_{EO2} and time to desaturation. Nevertheless, the margin of safety is tiny, no matter what technique is used.

Effects of the half-sitting position

In morbidly obese patients, the sitting position improves diaphragm kinetics, increases FRC, decreases the incidence of atelectasis and respiratory work, compared to the supine position.[24,25] These elements lead to an increase in oxygen reserves, a decrease in the shunt fraction with a better distribution of vascularization. As a result, there is better tolerance to apnea in the half-sitting position, with a higher p_{aO2} and a longer desaturation time. Practically speaking, the half-sitting position in morbidly obese patients makes intubation more difficult, which Dixon does not demonstrate in his study, and there is a potential loss of the benefit when the patient is repositioned in the supine position.[28] A halfway position allowing a respiratory gain, as well as intubation without a change in position, would be ideal.[7]

Effects of positive-end expiratory pressure (PEEP)

General anesthesia increases the intrapulmonary shunt even in healthy patients, mainly because of the occurrence of atelectasis. In 90% of cases, this appears within one minute following induction of anesthesia.[29] Atelectasis is more important in obese patients or when there is 100% F_{IO2} preoxygenation and causes a further decrease in the duration of non-hypoxemic apnea. Application of PEEP during preoxygenation, followed by manual ventilation when apnea occurs, prevents the occurrence of atelectasis in obese patients ventilated with 100% F_{IO2}.[30] There is more atelectasis in obese patients than in normal-weight subjects before anesthesia (2.1% vs 1%). The situation becomes worse after extubation (7.6% vs 2.8%). Obese patients continue getting worse, whereas healthy patients improve one day after surgery (9.7% vs 1.9%).[30]

TABLE 3: Comparison of preoxygenation techniques in obese patients

Study	Population	Compared techniques	Interventions	Results
Goldberg, 1989[16]	n = 13	TVB 3 min 4 DB	Measurement of CO_2	TVB 3 min > 4DB for time to desaturation
Rapaport, 2004[27]	n = 20	TVB 3 min 8 DB	8 DB → Hyperventilation	8 DB = TVB 3 min

TVB = normal breathing; DB = vital capacity breathing.

Ventilation of a sedated patient with PEEP may cause gastric insufflation and aspiration, as opposed to its use in an awake patient.[29] In studies where PEEP was applied during preoxygenation,[29,30] good patient tolerance to preoxygenation was observed.

PREOXYGENATION IN PREGNANT WOMEN

During pregnancy, the time needed to reach complete alveolar denitrogenation is shorter (104 ± 30 sec between 13-26 weeks and 80 ± 20 sec between 26-42 weeks) than in non-pregnant young women of similar morphology (130±30 sec). This is due to a significant reduction of FRC during pregnancy.[31] Desaturation during apnea is also faster.[6]

According to some studies,[32,33] the preoxygenation time for a Cesarean section could be shortened because 100% tidal volume O_2 ventilation during 3 min and the 4 DB 30 sec technique produce similar results regarding p_{aO2} or apnea time without desaturation. However, Russell et al[34] did not confirm these results by demonstrating that the slow technique was better with respect to the duration of apnea without desaturation (Table 4). It is worth mentioning that, in some women, according to several studies,[33] apnea can be approximately 60 seconds before desaturation, which is a particularly short period and carries an obvious risk. The half-sitting position does not improve the quality of preoxygenation in pregnant women.[6] This is mainly because the gravid uterus prevents a significant lowering of the diaphragm in the sitting position and there is a different fat distribution compared with morbidly obese patients.

PREOXYGENATION IN ELDERLY PATIENTS

The fast preoxygenation techniques have shown their inferiority when compared with TVB 3 min[15] in elderly patients (Table 5). In geriatrics, it is difficult to obtain the cooperation for fast preoxygenation techniques (forced inspiration and expiration). Moreover, several alterations in the respiratory system due to old age explain the ineffectiveness of fast preoxygenation techniques.[15] There is a reduction of the alveolar exchange surface that decreases alveolar oxygen diffusion. Decreased tissue elasticity results in early alveolar closure during forced expiration, even during normal expiration. The net effect is an increased shunt. Respiratory muscle weakness results in reduction in the strength and speed of contraction.[35]

MONITORING THE EFFICIENCY OF PREOXYGENATION

Pulse oximetry

An S_{pO2} value of almost 100% does not mean that preoxygenation is optimized; O_2 saturation of blood does not take into account the tissue reserves.

Expired fraction of oxygen

Denitrogenation induces oxygenation of the FRC, which then acts as an oxygen reserve to supply blood, which is a determining factor of the time to desaturation during apnea. The F_{EO2} is the best method to monitor preoxygenation.[2,14,32] If the F_{EO2} is < 90%, then it shows incomplete denitrogenation of the FRC. Its occurrence is 22.5% in healthy volunteers.

Arterial partial pressure of oxygen

Besides the impossibility of taking several samples, the p_{aO2} is a poor indicator of preoxygenation quality. A high p_{aO2} does not mean good preoxygenation. On the other hand, some patients for whom intubation is needed due to respiratory distress can show a low p_{aO2} even after appropriate preoxygenation.[37,38]

FAILURE TO PREOXYGENATE

Failure to preoxygenate may be due either to a leak around the mask,[22] or to too short a preoxygenation time. A leak is the major factor related to failure of preoxygenation and all techniques are equally ineffective in that case, with a peak F_{EO2} varying between 55% and 70%. This type of failure can be seen in 10% to 15% of non-edentulous patients without facial malformations. Practically

TABLE 4: Comparison of preoxygenation techniques in pregnant women

Study	Population	Compared techniques	Interventions	Results
Norris, 1985[33]	n = 14 Cesarean	TVB 3 min 4 DB	Measurement of p_{aO2}	TVB 3 min = 4 DB
Russell, 1987[34]	n = 30 Pregnant women	TVB 3 min 4 DB	Compared to a group of non-pregnant women	TVB 3min > 4 DB in pregnant women
Bernard, 1994[33]	n = 27 Cesarean	TVB 4 min 4 DB	No rebreathing Measure of desaturation time after intubation	TVB 4 min = 4 DB

TVB = normal breathing; DB = vital capacity breathing; p_{aO2} = partial pressure of oxygen in arterial blood.

TABLE 5: Comparison of preoxygenation techniques in elderly patients

Study	Population	Compared techniques	Interventions	Results
Valentine, 1990[15]	n = 24 Age > 65	TVB 3 min 4 DB	Measurement of desaturation time after intubation	TVB 3 min > 4DB
McCarthy, 1991[35]	n = 20	TVB 3 min 8 DB	Time until desaturation to 93% before intubation	TVB 1 min < 4 DB TVB 2, 3 or 4 min = 4 DB

TVB = tidal volume breathing; DB = Deep Breaths.

speaking, it is much more frequent in patients who are edentulous, have a beard or moustache, or those who are not very cooperative or have a gastric tube in place.[22] The occurrence of frank movements of the reservoir bag during each cycle, the presence of an expired CO_2 curve, and a P_{EO2} are indicative of a good airway seal.[11]

An intolerance to the face mask leads to a reduction in preoxygenation time. The unpleasantness of the mask is overestimated by the anesthesiologist (5/10) compared with the patient (2/10). This unpleasantness is similar to that provoked by insertion of a venous access.[39]

NEW TECHNIQUES

Nasopharyngeal oxygen supply

Oxygenation by nasopharyngeal oxygen supply during apnea and after slow preoxygenation delays postinduction hypoxemia and prolongs the time before desaturation.[40]

Mouth-circuit system

A mouthpiece through which the patient breathes directly is an alternative to the face mask. Its use by 50 volunteers[7] revealed a good airway seal as well as easy patient cooperation and understanding (no nasal breathing). In addition to instances when the face mask is not recommended (eg, cases of claustrophobia, burns, or facial traumas), it can be used in cases of ineffective preoxygenation in edentulous, bearded, or moustached patients.[41] A study of mouthpiece effectiveness based on the evolution of P_{EO2} increase with time[41] reveals that the mouthpiece improves fast preoxygenation in 4 DB 30 sec, which can be interesting for emergency induction. It improves 3 min slow oxygenation only when associated with a nose clip. It has no effect on 5 min slow oxygenation.

NASORAL system

The NASORAL device consists of a nose mask for inspiration linked to a fresh gas reservoir and a mouthpiece for expiration. This system allows a perfect airway seal and the absence of rebreathing, thanks to unidirectional valves. The drawbacks of this system are:[36]

- it is impossible to ventilate the patient postapnea and time is wasted while changing the device
- the system is difficult to use in children, people unable to breathe through their mouth,[36] and the elderly
- the F_{EO2} is similar to that of the face mask, even if it is reached faster. The incidence of a ≥90% F_{EO2} is similar to that of the face mask, ie, 75%.[36,42]

These arguments, added to the extra cost of the NASORAL system, hinder the introduction of this device in clinical practice.

CONCLUSION

Preoxygenation is of primary importance because it diminishes the risks of hypoxia after induction of anesthesia. The preoxygenation maneuver must be rigorously conducted by personnel sensitized to the importance of this seemingly trivial procedure. This will avoid finding the mask several centimeters away from the face or removed to allow the patient to talk.

KEY POINTS

- Preoxygenation offers life-saving extra time in cases of difficult ventilation and/or intubation.
- Preoxygenation is mandatory when induction of anesthesia involves a potential desaturation risk before control of the airway is obtained, and when problems with oxygenation are anticipated.
- There are two standard techniques for preoxygenation: a slow technique: tidal volume breathing (TVB) with an inspired fraction of oxygen (F_{IO2}) = 100% during 2 to 5 minutes; and fast techniques: 4 to 8 deep vital capacity breaths at F_{IO2} = 100% in 30 to 60 seconds (4-8 DB).
- No matter which technique is chosen, to preoxygenate obese patients, the margin of safety is low and in practice, allows only one laryngoscopy attempt.
- In obese patients, a change from the supine to the sitting position results in an increase in FRC, a diminished rate of atelectasis, and a reduction in respiratory work, all of which increase oxygen reserves.
- In some pregnant women, the apnea period before desaturation may be as short as 60 sec, an especially short time that carries obvious risks.
- Fast preoxygenation techniques are not as effective as TVB 3 min in elderly patients.
- Measuring the expired fraction of oxygen (F_{EO2}) is the best way to monitor preoxygenation.
- Failure of preoxygenation is due to failure to inhale 100% F_{IO2}, a short preoxygenation time, or a leak around the mask.
- There are no new systems applicable in current practice that demonstrate an obvious advantage over slow preoxygenation (TVB).

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