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Opinion

Pro-con debate on preoxygenation: Cons☆
We shall moderate the inspired oxygen concentration or avoid the fall in the resting lung volume when inducing anesthesia

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Preoxygenation, that is breathing 100% oxygen (O_2) for a few minutes prior to induction of anesthesia and continuing with 100% O_2 until the trachea has been intubated, is a safety procedure to reduce the risk of hypoxemia under a critical period of the anesthetic procedure [1]. It is obvious that the patient and the doctor or nurse demand as much safety as possible but since 100% O_2 almost inevitably causes atelectasis [2], one may ask if the standard preoxygenation procedure must be further refined. The procedure that is used today goes back to a time when the monitoring of vital function was less advanced than today. In particular, the efficiency of ventilation and oxygenation of the blood was mainly done by checking that gas was expired after a previous inflation of the lung and that skin color looked good. With increased understanding of the changes that occur during induction of anesthesia and with improved monitoring, a revision of the standard technique might be considered. We do not advocate anything less than a thorough preoxygenation in any situation where induction of anesthesia carries an increased risk, e.g. for emergency operations, during rapid sequence induction, or identification of a known or possible difficulty to intubate or ventilate.

Let us begin with a short summary of the changes in lung function that are caused by the standard preoxygenation and induction of anesthesia. Pure oxygen breathing for a couple of minutes will increase alveolar O_2 concentration to 90% or more in a patient with healthy lungs, [3]. When anesthesia is induced, the anesthetic reduces respiratory muscle tone that causes a decrease in the end-expiratory lung volume (EELV) [4]. This decrease will cause permanent (during the complete respiratory cycle) or intermittent (part of the respiratory cycle) airway closure in almost all subjects and the high oxygen concentration behind closed or semi-closed airways will be absorbed promoting collapse of alveoli (atelectasis) [5]. Thus, to cause atelectasis, the subject has to breathe high oxygen concentration and his or her EELV must be reduced to produce airway closure. If the patient is preoxygenated and anesthesia induced during ventilation with 100% O_2, atelectasis will appear within 5–7 min even if ventilation is switched to a lower O_2 concentration, e.g. 30–40%, as soon as the airway has been secured [3]. This is because the closed or semi-closed airways trap the gas that was used during the preoxygenation. With 80% O_2 during the preoxygenation some atelectasis may appear after 7–14 min and will increase further during 45 min after induction to the same size as after preoxygenation with 100% O_2 [3]. However, this slower appearance gives ample time to make a couple of deep inflations of the lungs so that airways are opened up and gas with lower oxygen concentration can enter the previously closed off units. If the subject is ventilated with air or 30% O_2 during this maneuver, assuming continued ventilation without a positive end-expiratory pressure (PEEP), atelectasis will not appear until after 6–9 (air) or 3 h (30% O_2) [6], i.e. after the completion of most operative procedures. Thus, atelectasis is a consequence of gas resorption behind closed or semi-closed airways, not by compression of lung tissue. The atelectasis causes shunt of blood flow through the lungs and impairment of oxygenation [7]. Moreover, atelectasis may promote an inflammatory process that, at least in theory, may cause postoperative lung complications [8,9]. It might also be mentioned that breathing pure oxygen increases vascular resistance, including coronary and cerebral vessels, which can hardly be considered a beneficial effect [10,11].

With the introduction of pulse oximetry, peripheral arterial oxygen saturation (SpO_2) can and shall be continuously monitored during anesthesia [12]. Any condition with impaired arterial

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oxygenation before the anesthesia can thus easily be detected and may prompt preoxygenation with 100% O_2, besides different steps to facilitate the intubation. SpO_2 should of course never be the only variable used to identify risk-patients. However, in elective surgery on stable patients where arterial oxygenation is good, the arterial O_2 content is satisfactory, metabolic demand is normal and the anesthetist or nurse considers mask ventilation and intubation of the trachea to be simple, then one may ask if a lower inspired oxygen can be used during the preoxygenation procedure. Indeed, breathing 80% oxygen is also a preoxygenation procedure! However, patients, who are considered to be difficult to ventilate or intubate, as identified in a clinical scoring system, or are prone to desaturate more easily, are to be given 100% O_2 during preoxygenation.

Thus, with professional assessment of the patient in a preanesthetic evaluation visit and adherence to strict criteria, using 80% O_2 during preoxygenation and induction might be reasonable.

If there is an impairment of SpO_2 during induction despite reasonable ventilation, then a switch to 100% O_2 is easy. The only situations when the patient (and the doctor and nurse) can benefit from preoxygenation with 100% O_2 from the start of anesthesia would be if bronchospasm has developed during induction or by the intubation procedure that will make it difficult to ventilate the patient, or if the patient, totally unexpectedly, cannot be ventilated before or after a failed first intubation attempt. Then 100% O_2 from the start gives more time before hypoxemia develops. The time for SpO_2 to fall to 90% during a lasting apnea averaged 411 s in normal weight patients during the induction of anesthesia with 100% O_2. If 80% O_2 had been used, the time had fallen to 303 s. The additional 2 min of "safe" saturation during apnea by using 100 instead of 80% O_2 is possibly enough to secure the airway in some but not all patients. To prolong the safe apnea time, additional oxygen can be provided via a nasopharyngeal catheter during the apneic period [13,14]. It also must be acknowledged that using the extra time offered by 100% O_2 for multiple attempts of intubation repeatedly has proven to be a dangerous strategy, turning a cannot intubate-can ventilate situation to a worst case scenario, i.e. cannot intubate – cannot oxygenate situation (CICO) [15–17]. The importance of using 80 or 100% O_2 during pre-oxygenation and induction in relation to the events leading to a CICO situation is probably of small significance. A normal intubation takes about a minute but if the first attempt fails there is still plenty of time for a second try after optimizing the conditions for intubation even with 80% O_2.

Another approach, that can increase the safety margin even more than during a standard preoxygenation procedure and at the same time avoid the formation of atelectasis, is to prevent the fall in EELV during the induction of anesthesia. If EELV is more or less preserved during the induction, airway closure will be prevented and no atelectasis should develop. Moreover, preservation of lung volume will increase the oxygen store at the alveolar level and thus prolong the time to hypoxemia in the event of apnea. In normal weight patients, using a continuous positive airway pressure (CPAP) of 6 cmH_2O, followed by a PEEP of 6 cmH_2O, increased the apnea tolerance time to 10 min, more than 2 min longer compared to no CPAP/PEEP during preoxygenation and induction and there was no or less atelectasis [18,19]. Collapse of alveoli seems not to occur during the limited time without any supportive airway pressure as during the intubation of the airway [18]. The advantage of using CPAP/PEEP during induction has also been proven in obese patients [20,21]. With an open lung during the continuing anesthesia oxygenation is facilitated. We acknowledge that there might be an increased risk of aspiration using PEEP during induction, inspiratory peak pressure including PEEP should not be more than 15 cm H_2O [22].

We may thus conclude that it is time to reconsider the standard preoxygenation procedure and realize that the standard procedure may not ensure maximum safety during induction of anesthesia, nor during the ensuing anesthesia and, possibly, postoperatively. Peri-operative hypoxemia and post-operative lung complications should be considered in the total evaluation of perioperative risks. The benefit of 100 instead of 80% O_2 is probably minor in a CICO situation but reducing atelectasis and post-operative lung complications may have a clear impact on morbidity and mortality [15]. Criteria, whether to use 100% O_2 or lower concentration e.g. 80% can be used in the preoperative clinical evaluation of the patient, limiting the use of 100% O_2 to risk patients. Finally, an optimum preoxygenation and induction of anesthesia process should be to prevent a fall in EELV during the induction of anesthesia by applying a CPAP of 6–10 cm H_2O and as soon as the airway is intubated the ventilation may continue, with a similar degree of PEEP, depending on the body mass index and volume status of the patient. If atelectasis has been prevented during the induction of anesthesia, it is likely that no atelectasis will develop during the anesthesia and surgery. However, physical compression of the lung during the surgery by e.g. pushing the diaphragm cranially may add to airway closure and collapse and a PEEP of a moderate level, e.g. 6–7 cm H_2O in a normal weight subject may help to prevent such collapse. Finally, and perhaps the most important part of the whole peri-operative anesthesia period, is the emergence from anesthesia. If atelectasis is prevented during induction and the whole anesthesia, any beneficial effect by these preventive measures may be lost if lung volume is reduced together with hyper-oxygenation during the emergence, because atelectasis is produced that will last into the postoperative period [23–25]. Emergence from anesthesia may thus be the most important part of the whole perioperative period but this is outside the scope of the present pro-con debate.

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