Anesthesiology
1999; 91:612–6

Preoxygenation

Comparison of Maximal Breathing and Tidal Volume Breathing Techniques

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Background: **Preoxygenation with tidal volume breathing for 3–5 min is recommended by Hamilton and Eastwood. This report compares tidal volume preoxygenation technique with deep breathing techniques for 30–60 s.**

Methods: **The study was conducted in two parts on patients undergoing elective coronary bypass grafting. In the first group (n = 32), each patient underwent all of the following preoxygenation techniques: the traditional technique consisting of 3 min of tidal volume breathing at an oxygen flow of 5 l/min; four deep breaths within 30 s at oxygen flows of 5 l/min, 10 l/min, and 20 l/min; and eight deep breaths within 60 s at an oxygen flow of 10 l/min. The mean arterial oxygen tensions after each technique were measured and compared. In the second group (n = 24), patients underwent one of the following techniques of preoxygenation: the traditional technique (n = 8), four deep breaths (n = 8), and eight deep breaths (n = 8). Apnea was then induced, and the mean times of hemoglobin desaturation from 100 to 99, 98, 97, 96, and 95% were determined.**

Results: **In the first group of patients, the mean arterial oxygen tension following the tidal breathing technique was 392 ± 72 mmHg. This was significantly higher ($P < 0.05$) than the values obtained following the four deep breath technique at oxygen flows of 5 l/min (256 ± 73 mmHg), 10 l/min (286 ± 69 mmHg), and 20 l/min (316 ± 67 mmHg). In contrast, the technique of eight deep breaths resulted in a mean arterial oxygen tension of 369 ± 69 mmHg, which was not significantly different from the value achieved by the traditional technique. In the second group of patients, apnea following different techniques of preoxygenation was associated with a slower hemoglobin desaturation in the eight-deep-breaths technique as compared with both the traditional and the four-deep-breaths techniques.**

Conclusion: **Rapid preoxygenation with the eight deep breaths within 60 s can be used as an alternative to the traditional 3-min technique. (Key words: Denitrogenation; hemoglobin desaturation; preoxygenation.)**

This article is accompanied by an Editorial View. Please see: Benumof JL: Preoxygenation: Best method for both efficacy and efficiency? ANESTHESIOLOGY 1999; 91:603–5.

PREOXYGENATION with 100% oxygen before rapid-sequence induction of anesthesia has become a standard practice. Preoxygenation depends on spontaneous breathing of 100% oxygen, which denitrogenates the functional residual capacity (FRC) of the lungs and hence increases the FRC oxygen store and delays the onset of arterial desaturation and hypoxemia during the apneic period following induction of anesthesia and muscle relaxation. Several studies have demonstrated that most subjects are optimally oxygenated after 3 min of normal tidal volume breathing of 100% oxygen using the standard breathing systems.[1,2]

In 1981, Gold *et al.*[3] showed that the mean arterial oxygen tension (Pa_{O_2}) after four deep breaths of 100% oxygen at 5 l/min within 30 s was not significantly different from the mean Pa_{O_2} value obtained after 3 min of normal tidal volume breathing. However, other studies have shown that the four-deep-breaths technique of preoxygenation is inferior to the traditional 3-min technique.[4,5] The decreased effectiveness of the four-breath technique may be attributed to nitrogen rebreathing, because the ventilation volume within 30 s markedly exceeds the oxygen flow used.[4] Thus, rapid preoxygenation by deep breathing may be optimized by increasing the oxygen flow or the preoxygenation time.

The present article reports a trial to assess the effect of different rapid preoxygenation techniques by deep breathing on the achieved Pa_{O_2}, as well as on the time of hemoglobin desaturation following the subsequent apnea associated with rapid-sequence induction of anesthesia and

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Received from the Department of Anesthesiology, American University of Beirut, Beirut, Lebanon. Submitted for publication January 19, 1999. Accepted for publication May 18, 1999. Support was provided solely from institutional and/or departmental sources.

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muscle relaxation. The results achieved by rapid preoxygenation are compared with those obtained by the traditional normal tidal volume preoxygenation technique.

Materials and Methods

The study was approved by an institutional review committee, and informed consent was obtained from all patients prior to initiation of the study. Two groups of patients were included in the study. The first group (group A) consisted of 32 patients and the second group (group B) consisted of 24 patients. All patients were scheduled for coronary artery bypass grafting and had no evidence of congestive cardiac failure or lung disease.

Patients were premedicated with intramuscular morphine (0.1 mg/kg) and promethazine (25 mg) on the day of the surgery. Peripheral oxygen saturation was monitored *via* a finger probe (HPM 1190A, Hewlett Packard, Boeblingen, Germany), and a radial artery was percutaneously cannulated in the operating room under local anesthesia (a room air arterial blood sample for blood gas analysis was obtained).

Group A

Each patient underwent five different techniques of preoxygenation and as such acted as his or her own control. The following preoxygenation techniques were investigated:

1. The traditional preoxygenation technique, which consists of 3 min of tidal volume breathing using an oxygen flow of 5 l/min;
2. Four deep breaths from FRC within 30 s using oxygen flows of 5 l/min, 10 l/min, and 20 l/min;
3. Eight deep breaths from FRC within 60 s using an oxygen flow of 10 l/min.

An adult Mapleson D circuit, with a 2-l capacity reservoir bag, was used for all techniques of preoxygenation. A 500-ml wide-bore tubing separates the face mask from the bag; the oxygen flow is delivered at the proximal end of the tubing near the face mask; and the exhalation valve is located at the distal end near the reservoir bag. Before preoxygenation, the reservoir bag was filled to capacity by occluding the mask opening with the palm of the hand. Patients were preoxygenated with a properly sized, tight-fitting anesthesia mask to prevent air leaks. These preoxygenation techniques were performed in a random order. Randomization was performed through a blinded pick from among five identical coins, each labeled according to one of the five preoxygenation techniques. A 5-min period of room air tidal volume breathing was allowed before each preoxygenation technique to ensure return of the arterial oxygen tension to its baseline value. An arterial blood sample was obtained before and after each preoxygenation technique and was analyzed for Pa_{O_2} (Radiometer ABL3, Copenhagen, Denmark).

Group B

The 24 patients were randomly divided (similarly to group A) into three subgroups who underwent one of the following preoxygenation techniques:

1. The traditional preoxygenation technique, which consists of 3 min of tidal volume breathing using an oxygen flow of 5 l/min;
2. Four deep breaths within 30 s using an oxygen flow of 5 l/min;
3. Eight deep breaths within 60 s using an oxygen flow of 10 l/min.

The details of the preoxygenation technique and the breathing circuit used were similar to those described for group A. At the end of the preoxygenation procedure, an arterial blood sample was withdrawn and Pa_{O_2} was determined.

Following the different techniques of preoxygenation, rapid-sequence induction of anesthesia was achieved by 2 mg/kg of thiopental, 1.5 μg/kg of sufentanyl, and 1.5 mg/kg of succinylcholine. Face-mask oxygenation was continued until apnea was obtained 15–30 s after the administration of the drugs. The face mask was then removed, the trachea intubated, and the proximal end of the tube left open to room air without any attempt at ventilation. The times to reach 99, 98, 97, 96, and 95% hemoglobin saturation were recorded. When the hemoglobin saturation reached 95%, the patients were connected to the ventilator.

Statistical Analysis

In group A, the mean Pa_{O_2} values obtained with each preoxygenation technique were compared using analysis of variance with repeated measures and the Scheffé test for pair-wise comparison. Statistical significance was considered at $P < 0.05$.

In group B, the mean times to reach 99 and 95% saturation were compared using the Student *t* test. Statistical significance was considered at $P < 0.05$.

Table 1. Pa_{O_2} on Room Air and at the End of Each of the Five Preoxygenation Techniques

Preoxygenation Technique	Baseline (Room Air)	After Preoxygenation
TVB (3 min, 5 l/min)	95 ± 22	392 ± 72*
4DB (30 s, 5 l/min)	87 ± 15	256 ± 73*†
4DB (30 s, 10 l/min)	90 ± 17	286 ± 67*†
4DB (30 s, 20 l/min)	91 ± 16	317 ± 67*†
8DB (60 s, 10 ll/min)	92 ± 19	369 ± 69*‡

Values are mean ± SD (mmHg).

TVB = traditional tidal volume breathing; 4DB = four-deep-breath technique; 8DB = eight-deep-breath technique.

* $P < 0.05$ *versus* room air.

† $P < 0.05$ *versus* 3 min, 5 l/min.

‡ $P = 0.11$ *versus* 3 min, 5 l/min.

Table 2. The Apnea-induced Hemoglobin Desaturation Times to 99% and 95% after the Three Preoxygenation Techniques

Change in Sp_{O_2}	3-min Normal Breathing	4 Deep Breaths in 30 s	8 Deep Breaths in 60 s
100–99%	3.21 ± 0.60*	2.22 ± 0.34†	4.40 ± 0.81
99–95%	0.61 ± 0.27	0.63 ± 0.34	0.87 ± 0.32
100–95%	3.73 ± 0.76*	2.78 ± 0.39†	5.21 ± 0.96

* $P < 0.05$ *versus* 4 deep breaths and 8 deep breaths.

† $P < 0.05$ *versus* 8 deep breaths.

Results

Group A

There were no significant differences among the mean Pa_{O_2} values before the various preoxygenation techniques (*i.e.*, on room air breathing) throughout the study. Following each preoxygenation technique, the mean Pa_{O_2} value was significantly greater ($P < 0.05$) than the corresponding value on room air tidal volume breathing (table 1).

Using the four-deep-breaths technique, increasing the oxygen flow from 5 to 10 and 20 l/min resulted in exponential increases of the mean Pa_{O_2} from the baseline value during breathing room air (fig. 1).

The mean Pa_{O_2} was significantly higher ($P < 0.05$) following 3 min of tidal volume breathing using an O_2 flow of 5 l/min, compared with the mean Pa_{O_2} values following four deep breaths within 30 s whether an O_2 flow of 5l/min, 10 l/min, or 20 l/min was used ($P < 0.05$). However, with the eight-deep-breaths technique within 60 s and using an oxygen flow of 10 l/min, the mean Pa_{O_2} value was not significantly different ($P = 0.11$) from that obtained at the end of 3 min of tidal volume breathing using an O_2 flow of 5 l/min (table 1).

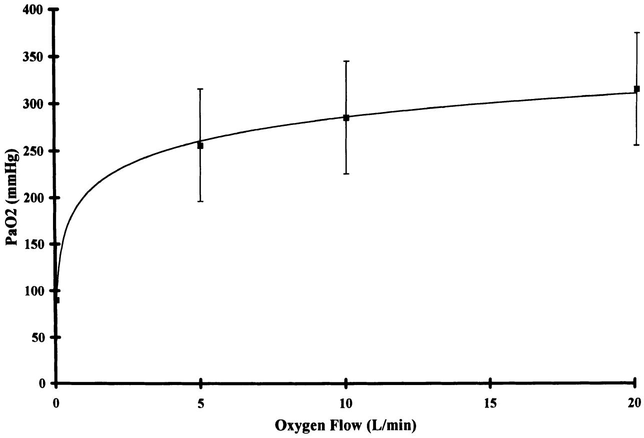

Fig. 1. Diagram showing the increase in arterial oxygen tension (Pa_{O_2}) from the mean baseline room air value caused by increasing the oxygen flow from 5 to 10 and 20 l/min. The hard line represents the logarithmic fit of Pa_{O_2} values *vs.* oxygen flow.

Group B

There was no statistically significant difference with respect to age, gender, height, and weight among the three different subgroups. The mean Pa_{O_2} value was significantly higher following the traditional preoxygenation technique (407 ± 53 mmHg) and the eight-deep-breaths preoxygenation technique (434 ± 45 mmHg), compared with the four-deep-breaths preoxygenation technique (250 ± 62 mmHg). However, there was no significant difference between the traditional technique and the eight-deep-breaths technique.

The mean times from the onset of apnea until hemoglobin saturation dropped from 100% to 95% are presented in table 2. The time for apnea-induced hemoglobin desaturation from 100 to 95% was significantly longer following the eight-deep-breaths preoxygenation technique compared with the traditional 3 min of tidal volume breathing, which is in turn significantly longer compared with the four-deep-breaths technique. The differences in the hemoglobin desaturation times among the three different techniques were caused primarily by the significantly different desaturation times from peripheral oxygen saturation of 100% to 99%; the desaturation times between 99% and 95% were not significantly different (fig. 2).

Discussion

In 1955, Hamilton and Eastwood[6] demonstrated that denitrogenation is 95% complete within 2–3 min if a subject is breathing at normal tidal volume from a circle

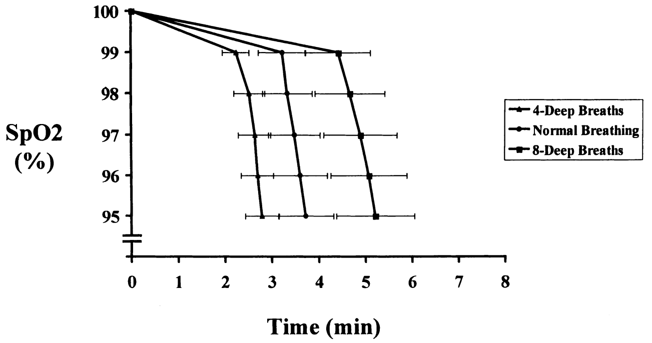

Fig. 2. Mean times to each percentage decrease in hemoglobin saturation during apnea after three different preoxygenation techniques.

anesthesia system with an oxygen flow of 5 l/min. These studies led to the recommendation that preoxygenation should last for 3–5 min before rapid-sequence induction of anesthesia. Preoxygenation before induction of general anesthesia increases the safe apnea time in most healthy adults to between 3 and 6 min before arterial oxygen desaturation occurs.[7]

Our results showed that the mean Pa_{O_2} after 3 min of tidal volume breathing at an oxygen flow of 5 l/min is significantly higher than the mean Pa_{O_2} obtained after four deep breaths within 30 s. This may be secondary to rebreathing. In patients taking four deep inspirations, the ventilation volume markedly exceeds the oxygen flow within 30 s. Consequently, rebreathing of exhaled nitrogen occurs, decreasing the inspired oxygen concentration.[4] On the other hand, in patients breathing tidal volume, preoxygenation decreases nitrogen concentration in the lungs to less than 4% within 3 min.[6]

The rate of nitrogen washout from semiopen circuits, such as Mapleson D, which allows rebreathing, is directly proportional to the fresh gas flow, as long as the subject breathes vigorously to move nitrogen from the alveoli into the breathing circuit. In our patients, if the four-deep-breaths technique was used for preoxygenation, increasing oxygen flow from 5 to 10 and 20 l/min produced exponential increases in the mean Pa_{O_2} values. Also, the degree of rebreathing that occurs with a Mapleson D circuit depends to some extent upon the pattern of breathing: The longer the expiratory pause, the more efficient is the circuit in segregating fresh gas from exhaled gas.[8] Thus, using large tidal volumes at a slow rate for preoxygenation may decrease rebreathing. However, preoxygenation with the four deep breaths within 30 s resulted, despite increasing the oxygen flow, in a significantly lower Pa_{O_2} than that achieved with the traditional preoxygenation technique.

Preoxygenation by the deep-breath technique may be improved by prolonging the time of deep breathing from 30 to 60 s, which allows eight deep breaths, and using an oxygen flow of 10 l/min. This approach can increase the ventilation volume to 8–9 l/min, which is about three times the FRC associated with an increase of the oxygen flow. The technique minimizes nitrogen rebreathing and ensures rapid washout of the FRC. Our study shows that the mean Pa_{O_2} with deep breathing for 60 s at an oxygen flow of 10 l/min is significantly higher than that obtained with the four deep breaths at an oxygen flow of 5, 10, or even 20 l/min and is comparable to the value obtained with the traditional 3-min technique of tidal volume breathing.

Given that the aim of preoxygenation is actually denitrogenation, the end-tidal oxygen is probably the best "surrogate marker."[9,10] Pa_{O_2} may be also taken as a surrogate marker for preoxygenation, because Pa_{O_2} is proportional to the alveolar P_{O_2} in the FRC, which is the main oxygen store. However, the only reason that we perform preoxygenation maneuvers is to attempt to increase the oxygen body stores and to prevent hemoglobin desaturation, and this is obviously a function of more than acute changes in Pa_{O_2}.[9,10] Thus, the time to desaturate is a more appropriate outcome measure for the efficiency of preoxygenation.

The differences found in Pa_{O_2} for all preoxygenation techniques have a minor impact on the arterial oxygen saturation, but because of the time differences among the different techniques, venous and tissue oxygen contents may be significantly different.[9,11] Thus, it is possible that the rapid techniques of preoxygenation may result in rapid arterial oxygenation without a significant increase in the tissue oxygen stores and hence result in more rapid hemoglobin desaturation during subsequent apnea than would a longer period of "traditional" preoxygenation.[9,11] Previous reports have shown that the four-deep-breaths technique is inferior to the 3-min technique,[4,5] particularly in pregnant patients,[5] who have decreased FRC and increased basal oxygen requirement, making them more prone to hypoxia. Also, the traditional 3-min technique of preoxygenation may be more suitable for obese patients who already have reduced FRC than the four-breath technique. Russell *et al.*[12] urged the use of at least 3 min of tidal volume breathing for preoxygenation of all high-risk patients.

Our report shows that rapid preoxygenation by the eight-deep- breaths technique within 60 s is superior to the four-deep-breaths technique within 30 s, because it resulted not only in a higher Pa_{O_2}, but also in a slower hemoglobin desaturation following subsequent apnea. The eight-deep-breaths preoxygenation technique resulted in Pa_{O_2} levels comparable to that achieved by the "traditional" technique. In addition, and to our surprise, rapid-sequence induction of anesthesia following the eight-deep-breaths preoxygenation technique was even associated with a significantly slower hemoglobin desaturation than following the traditional preoxygenation by tidal volume breathing for 3 min.

The slower desaturation following the eight-deep-breaths preoxygenation technique compared with the traditional technique, despite the comparable Pa_{O_2} values following preoxygenation, was unexpected. In both techniques, preoxygenation was followed by induction of anesthesia and neuromuscular blockade, which resulted in apnea after 15–30 s, during which face-mask oxygenation was maintained. Denitrogenation of the lungs is an exponential function.[9] Thus, it is possible that the extra 15–30 s provided more denitrogenation and alveolar oxygenation in patients breathing deeply for 60 s than in patients breathing normal tidal volumes for 3 min. Also, it is possible that continued maximal breathing during the extra time may open collapsed airways or lung tissues, with a consequent increase of the oxygen store in the FRC.

In conclusion, rapid preoxygenation can be achieved by using eight deep breaths within 60 s at an oxygen flow of 10 l/min. This technique can produce Pa_{O_2} values comparable to that achieved by the "traditional" preoxygenation technique. Also, it delays the onset of subsequent apnea-induced hemoglobin desaturation more significantly than that following the other techniques of preoxygenation. Hence, the eight-deep-breaths technique may be used as an alternative to the traditional technique of preoxygenation in patients undergoing rapid-sequence induction of anesthesia, as well as in other circumstances in which tracheal intubation or ventilation may be difficult to achieve.

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