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Preoxygenation Is More Effective in the 25° Head-up Position Than in the Supine Position in Severely Obese Patients

A Randomized Controlled Study

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Background: **Class III obese patients have altered respiratory mechanics, which are further impaired in the supine position. The authors explored the hypothesis that preoxygenation in the 25° head-up position allows a greater safety margin for induction of anesthesia than the supine position.**

Methods: **A randomized controlled trial measured oxygen saturation and the desaturation safety period after 3 min of preoxygenation in 42 consecutive (male:female 13:29) severely obese (body mass index > 40 kg/m^2) patients who were undergoing laparoscopic adjustable gastric band surgery and were randomly assigned to the supine position or the 25° head-up position. Serial arterial blood gases were taken before and after preoxygenation and 90 s after induction. After induction, ventilation was delayed until blood oxygen saturation reached 92%, and this desaturation safety period was recorded.**

Results: **The mean body mass indexes for the supine and 25° head-up groups were 47.3 and 44.9 kg/m^2, respectively (P = 0.18). The group randomly assigned to the 25° head-up position achieved higher preinduction oxygen tensions (442 ± 104 *vs.* 360 ± 99 mmHg; P = 0.012) and took longer to reach an oxygen saturation of 92% (201 ± 55 *vs.* 155 ± 69 s; P = 0.023). There was a strong positive correlation between the induction oxygen tension achieved and the time to reach an oxygen saturation of 92% (r = 0.51, P = 0.001). There were no adverse events associated with the study.**

Conclusion: **Preoxygenation in the 25° head-up position achieves 23% higher oxygen tensions, allowing a clinically significant increase in the desaturation safety period—greater time for intubation and airway control. Induction in the 25° head-up position may provide a greater safety margin for airway control.**

AS a result of the current obesity epidemic, anesthetists are more commonly confronted with the challenge of anesthetizing severely obese patients. The technical challenges and risks of anesthesia in obese individuals are appreciably higher than those of healthy-weight individuals.[1,2]

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There are a number of features of severely obese patients that increase the risk of hypoxia during the induction period. Severe obesity, especially in men, is associated with an increased risk of difficult tracheal intubation and delay in securing the airway.[1,3–6] In addition, increasing body mass index (BMI) is associated with a more rapid decrease in oxygen saturation during periods of apnea under anesthesia.[7] This decrease is likely to be related to increased metabolic rate, and hence greater oxygen consumption, and impaired respiratory mechanics leading to reduced oxygen reserves.[3,8]

Obese individuals have been shown to have a decrease in lung and chest wall compliance, increased airway resistance, and a reduced functional residual capacity (FRC).[9,10] This is likely to be explained by the mechanical effect of increased fat within the chest wall, abdominal wall, and abdomen, which combine to compress the thoracic cage, diaphragm, and lungs. The resultant impairment of diaphragmatic descent reduces FRC, which in turn increases airway resistance.[11] Closure of airways leads to alveolar collapse, ventilation/perfusion mismatch, and hypoxia induced by shunting.[12,13]

Arterial oxygen saturation (Sa_{O_2}) and FRC are reduced when obese patients assume the supine position.[14–16] These abnormalities are further exaggerated with induction of anesthesia, probably because of reduction in the tone of the diaphragm.[15] Boyce *et al.*[17] have demonstrated that the decrease in oxygen saturation during apnea under anesthesia is slower when the patient is positioned head-up as compared with the flat supine position. Positioning the patient's head up 45° was shown to facilitate weaning from mechanical ventilation, with increased tidal volumes and lower respiratory rates, in comparison to positioning at 0 or 90°.[18]

The aim of preoxygenation before anesthesia is to maximize intrapulmonary oxygen reserves, allowing prolonged apnea without a critical reduction in oxygen saturation. Preoxygenation with 100% oxygen is often used before induction of anesthesia to allow greater time to secure the airway. Preoxygenation in a more upright posture may provide more oxygen storage in a larger lung volume and reduce the tendency to atelectasis and

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shunting, making oxygenation more efficient. We hypothesize that posture may influence the effectiveness of preoxygenation in severely obese patients, in particular that a head-up posture would provide better preoxygenation when compared with the supine position.

Using a randomized controlled trial format, we assessed whether preoxygenation of severely obese patients in the 25° head-up position would improve preinduction oxygenation when compared with the more conventional supine position. Furthermore, the desaturation safety period (DSP), defined as the time of apnea from induction of anesthesia until the oxygen saturation decreased to 92%, was extended in the 25° head-up position when compared with the supine position.

Materials and Methods

The study was conducted with signed informed consent of the participants in accordance with the Declaration of Helsinki, with approval of The Avenue Hospital's (Melbourne, Victoria, Australia) institutional review board.

Forty-two patients presenting for laparoscopic adjustable gastric band surgery were randomly assigned, for preoxygenation and induction of anesthesia, to either the supine or 25° head-up position. The 25° to the horizontal, as measured by a builder's inclinometer calibrated with a spirit level, was achieved by breaking the operating table at the hips to prevent patients from sliding off the table. Significantly, the surgical procedure is performed with the patient in this 25° head-up position. Each participant was anesthetized by one of two anesthetists with extensive experience in severely obese patients. Consecutive patients aged between 18 and 60 yr, with a BMI greater than 40 kg/m^2, were approached to participate in the study. Approximately 80% of patients undergoing laparoscopic gastric banding are female, so to allow for sex balance, up to 30 female participants and at least 12 male participants were recruited. Position was allocated randomly using a computer-generated system, 30 for women and 20 for men.

The exclusion criteria were significant asthma or obstructive airway disease, a history of ischemic heart disease, cerebrovascular disease, failed or difficult intubation, or known cholinesterase deficiency and a Mallampati score[19] of greater than 2. If any difficulty with the patient was encountered during induction, the anesthetist would take all appropriate action to optimize patient care, and the patient would be excluded from the study.

Each patient fasted for 6 h before the procedure. All received standard oral premedication of temazepam, ranitidine, and paracetamol and then had an intravenous cannula inserted and intravenous Hartmanns commenced. Before induction, a baseline arterial blood gas measurement was taken from an arterial line placed in the radial artery for analysis (AVL Scientific Corporation OPTI CCA, Roswell, GA). Preoxygenation with 100% oxygen was conducted for 3 min, and all patients were asked to breathe normally during this period. An arterial blood sample was taken immediately before and after the period of preoxygenation. Midazolam, 2 mg, and fentanyl were given intravenously immediately before a standardized rapid sequence induction, using propofol as the induction agent and suxamethonium, with each subject in their assigned position. The Sellick maneuver (cricoid pressure) was used to protect the airway, and the patient underwent intubation after fasciculation. To ensure a satisfactory endotracheal tube position, one small (approximately 200 ml) breath of 100% oxygen was provided so that an end-tidal carbon dioxide trace was recorded.

The endotracheal tube was then disconnected, and no ventilation occurred until oxygen saturation levels reached 92% (Datex AS3, Helsinki, Finland). On achieving an oxygenation saturation of 92%, positive-pressure ventilation with 100% oxygen was commenced immediately. Another arterial blood sample was taken 90 s after induction (desaturation phase). The DSP was defined as the time taken to reach an oxygen saturation of 92% from the time of induction. The recovery period was defined as the time for the oxygen saturation to reach 97% after initiation of ventilation, and the minimal oxygen saturation during the recovery period was recorded. A fourth arterial sample for blood gases was taken 120 s after the commencement of ventilation (recovery phase). Full routine monitoring, including blood pressure, pulse rate, pulse oximetry, electrocardiography, and end tidal carbon dioxide monitoring, were recorded throughout the procedure. Any use of medication to modify blood pressure during the procedure was also recorded. A propofol infusion was used to maintain anesthesia during the period of the experimental protocol.

In addition to age and sex, several preoperative anthropometric measurements, including height and weight as BMI (kg/m^2); neck circumference (measured at the level of the cricothyroid cartilage), waist, and hip measurements; and lung function measures, were used in evaluating predictors of key outcome measures including arterial oxygen tension and the DSP. Lung function tests were performed on all patients preoperatively using a Sensormedics Vmax 22 system (Sensormedics Inc., Yorba Linda, CA) and included lung volume and flow loop spirometry.

Statistics

The power of the study was calculated using the time to reach a desaturation of 92%, this parameter being the key outcome measure. An $\mathrm{Sa_{O_2}}$ of 92% was an arbitrary choice but was chosen because it was considered safe to allow controlled desaturation to this level. An additional 30 s or more before reaching an oxygen saturation of 92% was considered clinically significant, allowing the anesthetist a greater safety buffer during induction of anesthesia. Using data from a previous study of controlled apnea during anesthesia in the supine and head-up positions in severely obese patients, we calculated that we would need to randomly assign a total of 42 patients to one of the two positions to have a 95% probability of detecting a 30-s difference between groups with a power of 0.8.[17] Therefore, we planned to recruit subjects until 42 had successfully completed the study protocol.

Data were analyzed according to the position to which the patients were randomly assigned (intention-to-treat analysis). Demographic data were compared using the chi-square test or independent sample Student *t* test as appropriate. Outcome measures were normally distributed and allowed for parametric analysis. Comparative outcomes were analyzed using the independent Student *t* test for continuous data and the chi-square test for categorical data. Linear regression analysis was used to assess the effect of patient position on the DSP and oxygen concentration after correcting for age, sex, and BMI. Binary logistic regression was used to find associations with binary variables. Bivariate correlation was assesses using Pearson correlation coefficients. SPSS (Chicago, IL) statistical software was used for statistical analysis. A P value of less than 0.05 was considered significant.

Results

The characteristics of the 42 participants in the study are detailed in table 1. There were no significant differences between the patients randomly assigned to the supine and 25° head-up positions for any of the variables tested. Because the supine group tended to be slightly older and tended to have a slightly higher BMI, any differences between the supine and 25° head-up groups were reassessed after controlling for possible confounders, such as age, BMI, and sex. A total of 44 patients were recruited, but two were excluded as a result of unsatisfactory arterial access. There were no exclusions for adverse events during the experimental phase of the study. Only one eligible candidate did not wish to take part in the study. There were no occasions when difficulty during induction led to withdrawal of a patient from the study. None of the patients were observed to breathe spontaneously during the DSP.

Table 1. Baseline Characteristics of Patients, Including Demographics, Anthropometrics, Lung Volume, and Spirometry

	25° Head-up (Mean, Median, or %)	Supine (Mean, Median, or %)	*P* Value
Number	21	21	
Age, yr	41.4 ± 6.4	44.8 ± 9.6	0.18
% Male, n	28.6 (6)	33.3 (7)	0.74
BMI, kg/m^2	44.9 ± 6.2	47.3 ± 6.7	0.18
Weight, kg	127.2 ± 18.0	134.7 ± 24.1	0.27
Waist circumference, cm	125.3 ± 10.0	130.2 ± 11.1	0.10
Neck circumference, cm	43.0 ± 3.5	43.5 ± 3.6	0.65
TLC % predicted	90.8 ± 8.7	89.6 ± 10.2	0.66
RV % predicted	77.8 ±	85.6 ± 19.2	0.18
FRC % predicted	62.6 ± 11.8	56.5 ± 10.8	0.12
FEV$_1$/FVC %	81.7 ± 5.3	81.1 ± 4.9	0.76

Continuous variables are presented as mean ± SD, and *P* values were calculated using the Student *t* test. For categorical variables, *P* values were calculated using the chi-square test.

BMI = body mass index; FEV$_1$ = forced expiratory volume in 1 s; FRC = functional residual capacity; FVC = forced vital capacity; RV = residual volume; TLC = total lung capacity.

Desaturation Safety Period

After induction of anesthesia, the DSP was 201 ± 56 s in the group preoxygenated in the 25° head-up position, which was significantly longer than 155 ± 70 s for the supine group ($P = 0.02$; table 2 and fig. 1). This provided a clinically relevant 46 s of additional time before reaching this level of saturation. Linear regression multivariate analysis revealed the position for preoxygenation explained significant variance in DSP when controlled for age, sex, and BMI ($r^2 = 0.12$, $P = 0.03$). Higher BMI, however, did reduce the time taken to reach a saturation of 92% ($r = -0.34$, $P = 0.03$). There were no other preoperative demographic or lung function measures that significantly influenced the DSP. Seven subjects had a DSP of less than 90 s, that is before the time of the third arterial blood gas collection. Six of the seven were randomly assigned to and preoxygenated in the supine position (chi-square $P = 0.04$). Binary logistic regression showed that the position for preoxygenation was the only predictor of this group. Not surprisingly, the DSP was strongly related to the oxygen tension achieved after preoxygenation ($r = 0.51$, $P = 0.001$; fig. 2). The position for preoxygenation did not influence the lowest

Table 2. The Desaturation Safety Period, Lowest Sao$_2$ and Time Taken to Achieve an Sao$_2$ of Greater Than 97% after the Commencement of Ventilation

	25° Head-up (Mean, Median, or %)	Supine (Mean, Median, or %)	*P* Value
DSP	201 ± 56	155 ± 70	0.02
Lowest Sao$_2$ after DSP, %	85.9 ± 3.0	85.0 ± 3.7	0.41
Time to reach Sao$_2$ of 97%, s	37.1 ± 11.6	33.9 ± 12.2	0.39

The desaturation safety period (DSP; time taken from induction to reach arterial oxygen saturation (Sao$_2$) of 92%) was measured. Ventilation was then commenced, and the lowest Sao$_2$ and the recovery time taken to achieve Sao$_2$ of 97% were recorded.

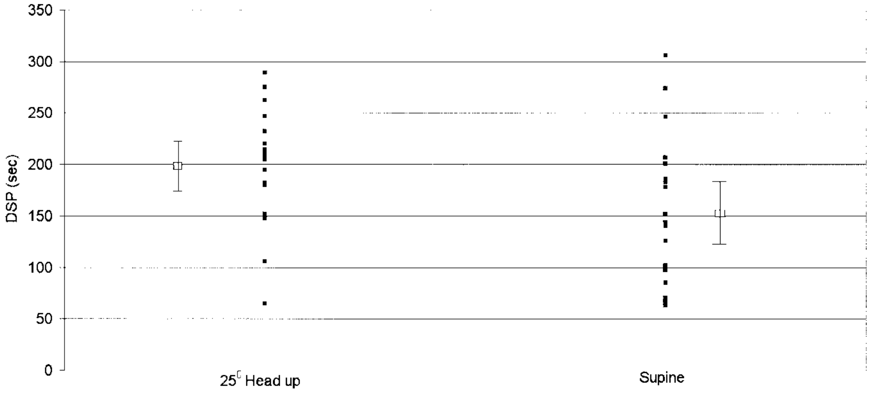

Fig. 1. Individual desaturation safety period (DSP; in seconds) for all subjects, grouped by position of randomization. Mean values ± 95% confidence intervals of the mean for both groups are also shown (P = 0.02).

oxygen saturation recorded after the commencement of active ventilation or the time taken to achieve an arterial oxygenation saturation of 97% (table 2).

Blood Gases

Subjects randomly assigned to the 25° head-up position achieved a significant 23% higher mean oxygen tension after 3 min of preoxygenation (table 3 and fig. 3). The assigned position had a significant influence on the oxygen tension achieved after controlling for age, sex, and BMI (r = 0.39, P = 0.01). Two independent factors predicted a higher oxygen saturation after preoxygenation; these were female sex and the 25° head-up position (combined r^2 = 0.30, P = 0.004). Men achieved a lower mean oxygen tension after preoxygenation (350 ± 116 mmHg) than women did (424 ± 99 mmHg; P = 0.04). Anthropometric and lung function measures did not significantly influence this oxygen tension. Six subjects did not achieve a preoxygenation saturation of 300 mmHg; of these, five were in the supine group (P = 0.08). These 6 subjects included 4 of 13 men (31%) and 2 of 29 women (7%) in the study (P = 0.04). Forty-two

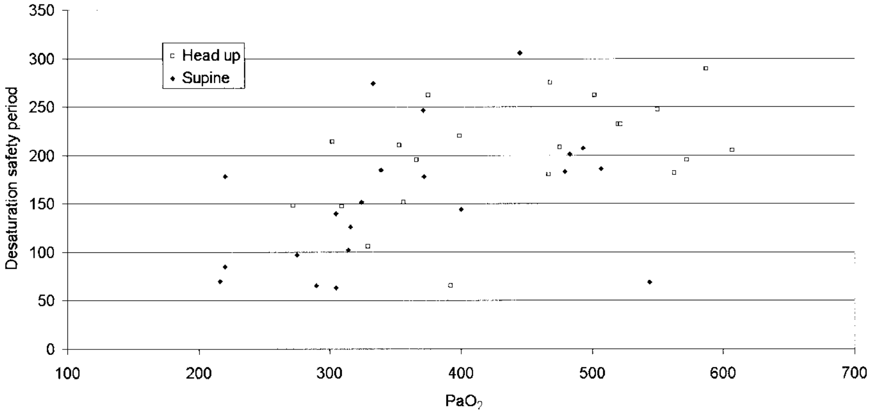

Fig. 2. Relation between oxygen tension (Pao_2) after preoxygenation and desaturation safety period to follow (r = 0.51, P = 0.001 for groups combined). ***Black diamonds*** **= head-up position;** ***open squares*** **= supine position.**

Table 3. Comparison of Blood Gas Results for Patients Randomly Assigned to the Supine and 25° Head-up Positions

	1	2	3	4
Oxygen, mmHg				
Supine	86.4 ± 9.6	359 ± 99	216 ± 160	383 ± 140
Head-up	92.5 ± 11.8	442 ± 104	308 ± 147	366 ± 109
P value	0.07	0.01	0.06	0.68
Carbon dioxide, mmHg				
Supine	39.1 ± 4.6	38.9 ± 4.6	48.3 ± 6.6	44.6 ± 6.2
Head-up	37.6 ± 4.2	37.0 ± 5.3	47.4 ± 5.3	42.5 ± 6.3
P value	0.25	0.24	0.63	0.57
pH				
Supine	7.45 ± 0.02	7.45 ± 0.03	7.37 ± 0.03	7.41 ± 0.04
Head-up	7.44 ± 0.02	7.44 ± 0.04	7.37 ± 0.03	7.40 ± 0.04
P value	0.36	0.84	0.91	0.27

Data are presented as mean ± SD; *P* values were calculated using the Student *t* test.

1 = Baseline, before preoxygenation; 2 = After 3 min of preoxygenation with 100% oxygen; 3 = 90 s after induction–suxamethonium dose; 4 = 120 s after commencement of active ventilation.

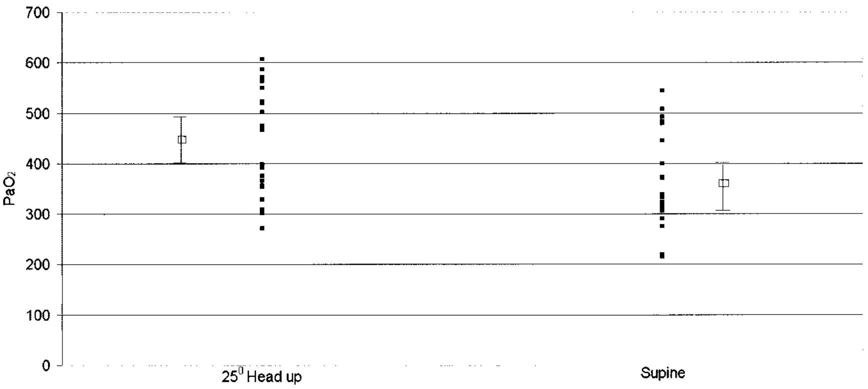

Fig. 3. Individual arterial oxygen tensions (Pa_{O_2}) after preoxygenation for all subjects, grouped by position of randomization. Mean values ± 95% confidence intervals of the mean for both groups are also shown ($P = 0.01$).

percent of the men randomly assigned to the supine position did not reach an oxygen tension of 300 mmHg after preoxygenation ($P = 0.02$).

Patient position did not make a significant difference for other blood gas results (table 3). The oxygen tension in the 25° head-up patients tended to be higher 90 s after induction ($P = 0.06$). Patient position did not influence the blood gases 2 min after positive-pressure ventilation had been established (blood gas 4).

The DSP was strongly and independently related to the preoxygenation oxygen tension achieved and the decrease in tension during next 90 s (combined $r^2 = 0.60$, $P < 0.001$). Of interest, there was no significant relation between the oxygen saturation achieved with preoxygenation and the change in the next 90 s. There are many factors that could possibly affect the change in saturation during 90 s of apnea. In a multivariate analysis including demographic, anthropometric, biochemical, and lung function variables, none had a significant relation with the change in oxygen saturation during the 90-s period.

Adverse Events

There were no adverse events reported during the study. The position used for preoxygenation and induction did not influence mean systolic or diastolic blood pressure, or pulse rate during the induction and early anesthetic period. None of the patients experienced hypotension, and none received pressor agents during the experimental phase of anesthesia.

The two anesthetists participating in this study, both with extensive experience in anesthetizing severely obese subjects, found some challenges with the unconventional 25° head-up position, and it required some innovation, but the anesthetists did not report increased difficulty with intubation. In addition, there was a perception that the 25° head-up position provided better positioning of the head for optimal intubation and better access to the airway by gravitational retraction of breast tissue. The anesthetists required a small footstool to achieve an adequate position to intubate the patients. There were no differences in any study outcome measures when comparing the patients grouped by treating anesthetist.

Discussion

The extended DSP indicates that the 25° head-up position may provide additional safety when compared with the flat supine position in severely obese subjects. Our findings complement those of Boyce *et al.*,[17] who demonstrated that the decrease in oxygen saturation during apnea under anesthesia is slower when the patient is positioned head-up as compared with flat; however, arterial blood gases were not measured in this study. It is notable that after ventilation was established, we did not find that patient position influenced arterial oxygen tension after 2 min. This finding suggests that any advantages with regard to lung function, atelectasis, and shunting in the 25° head-up position are lost when positive-pressure ventilation is commenced. The current study also differs from the study of Boyce *et al.* in some key areas. We measured the DSP immediately after preoxygenation and induction of anesthesia to optimally mimic the reality of apnea during the time when the anesthetist would be securing a difficult airway, whereas in the study of Boyce *et al.*, ventilation was ceased 5 min after mechanical ventilation with 50% oxygen.

Obese patients present greater challenges to the anesthetist, and there is no doubt that, if difficulty is encountered, the time available until critical hypoxemia is greatly reduced. Jense *et al.*[7] showed that after 5 min of preoxygenation, the time taken to desaturate to an Sa_{O_2} of 90% was significantly shorter in obese patients. Regression analysis showed a significant negative linear correlation between time to desaturation and increasing obesity ($r = -0.83$). The current study confirms the relation between increasing BMI and shorter DSP in patients with a BMI of greater than 40 kg/m^2. In addition, we demonstrated that by simply altering the position of the patient during preoxygenation, we can prolong the DSP, allowing valuable extra time for securing the airway.

We may have better modeled the emergency situation of total airway obstruction by clamping the endotracheal tube after checking that it was in the correct position. In this situation, the DSP measured may be shorter than what we measured because the communication between air and the lung would have allowed apneic oxygenation, which may have reduced the development of atelectasis and associated ventilation/perfusion mismatch.

It is important to recognize that sex also seems to be relevant. Obese males present a high risk of difficulty with intubation.[3] We have found that the supine position and male gender are predictors of poor preoxygenation. Men therefore present a greater risk of critical hypoxia if intubation difficulties are encountered. In view of this greater risk, severely obese males may benefit most from a change to preoxygenation in the 25° head-up position. The reason for the poorer oxygen tension achieved in men is unclear. Preoperative lung function and volumes were similarly impaired in the upright posture in both men and women, but our findings suggest that there may be greater postural impairment of lung function in men.

Further investigation is required to find the most practical and efficacious position for preoxygenation before anesthesia. Optimizing lung oxygen content is likely to be achieved by a posture that improves respiratory mechanics, lung volumes, FRC, and arterial oxygen tension after preoxygenation. An angle of 25° is readily achievable, but similar physiologic gains may be possible at a lesser angle while allowing intubation to take place in a more familiar position. Alternatively, a greater angle of inclination may produce more efficient preoxygenation; however, this angle may be associated with more practical difficulties. Finally, the patient's posture could be changed after preoxygenation, just before induction, from a head-up or sitting position to the more familiar supine position for intubation. Although oxygen tensions may be high in this situation, there may be some loss of benefit associated with a change to the supine position for intubation due to a reduction in FRC, which may shorten the DSP.

In the current study, we show that the DSP is strongly related to the oxygen tension achieved after preoxygenation, indicating that the level of arterial oxygenation is likely to be an important determinant of the DSP. The oxygen tension at this time represents the effectiveness of preoxygenation, and therefore, further studies of patient preoxygenation and posture could use this single oxygen tension as a potentially useful predictor for the DSP or safety margin.

There are many other clinical circumstances in which respiratory function may be impaired in the supine posture, *e.g.*, advanced pregnancy, ascites, bowel obstruction. Preoxygenation in a position that is more effective in the obese may also be more effective in these circumstances.

In conclusion, this study demonstrates that, in class III obese patients, position during preoxygenation influences the time before significant oxygen desaturation occurs. This provides the potential for improving the safety of anesthesia in these subjects. Further studies are required to optimize this effect in obese subjects and to explore potential benefit in other "at risk" clinical circumstances.

References

1. Williamson JA, Webb RK, Szekely S, Gillies ER, Dreosti AV: The Australian Incident Monitoring Study. Difficult intubation: An analysis of 2000 incident reports. Anaesth Intensive Care 1993; 21:602–7
2. Shenkman Z, Shir Y, Brodsky JB: Perioperative management of the obese patient. Br J Anaesth 1993; 70:349–59
3. Rose DK, Cohen MM: The airway: Problems and predictions in 18,500 patients. Can J Anaesth 1994; 41:372–83
4. Wilson ME, Spiegelhalter D, Robertson JA, Lesser P: Predicting difficult intubation. Br J Anaesth 1988; 61:211–6
5. Brodsky JB, Lemmens HJ, Brock-Utne JG, Vierra M, Saidman LJ: Morbid obesity and tracheal intubation. Anesth Analg 2002; 94:732–6
6. Ezri T, Medalion B, Weisenberg M, Szmuk P, Warters RD, Charuzi I: Increased body mass index per se is not a predictor of difficult laryngoscopy. Can J Anaesth 2003; 50:179–83
7. Jense HG, Dubin SA, Silverstein PI, O'Leary-Escolas U: Effect of obesity on safe duration of apnea in anesthetized humans. Anesth Analg 1991; 72:89–93
8. Huang KC, Kormas N, Steinbeck K, Loughnan G, Caterson ID: Resting metabolic rate in severely obese diabetic and nondiabetic subjects. Obes Res 2004; 12:840–5
9. Koenig SM: Pulmonary complications of obesity. Am J Med Sci 2001; 321:249–79
10. Rochester DF, Enson Y: Current concepts in the pathogenesis of the obesity-hypoventilation syndrome: Mechanical and circulatory factors. Am J Med 1974; 57:402–20
11. Yap JC, Watson RA, Gilbey S, Pride NB: Effects of posture on respiratory mechanics in obesity. J Appl Physiol 1995; 79:1199–205
12. Barrera F, Hillyer P, Ascanio G, Bechtel J: The distribution of ventilation, diffusion, and blood flow in obese patients with normal and abnormal blood gases. Am Rev Respir Dis 1973; 108:819–30
13. Holley HS, Milic-Emili J, Becklake MR, Bates DV: Regional distribution of pulmonary ventilation and perfusion in obesity. J Clin Invest 1967; 46:475–81
14. Hedenstierna G: Gas exchange during anaesthesia. Br J Anaesth 1990; 64:507–14
15. Pelosi P, Croci M, Calappi E, Mulazzi D, Cerisara M, Vercesi P, Vicardi P, Gattinoni L: Prone positioning improves pulmonary function in obese patients during general anesthesia. Anesth Analg 1996; 83:578–83
16. Hakala K, Maasilta P, Sovijarvi AR: Upright body position and weight loss improve respiratory mechanics and daytime oxygenation in obese patients with obstructive sleep apnoea. Clin Physiol 2000; 20:50–5
17. Boyce JR, Ness T, Castroman P, Gleysteen JJ: A preliminary study of the optimal anesthesia positioning for the morbidly obese patient. Obes Surg 2003; 13:4–9
18. Burns SM, Egloff MB, Ryan B, Carpenter R, Burns JE: Effect of body position on spontaneous respiratory rate and tidal volume in patients with obesity, abdominal distension and ascites. Am J Crit Care 1994; 3:102–6
19. Voyagis GS, Kyriakis KP, Dimitriou V, Vrettou I: Value of oropharyngeal Mallampati classification in predicting difficult laryngoscopy among obese patients. Eur J Anaesthesiol 1998; 15:330–4