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ORIGINAL ARTICLE

# Higher fraction of inspired oxygen in anesthesia induction does not affect functional residual capacity reduction after intubation: a comparative study of higher and lower oxygen concentration

**Akihiro Kanaya · Daizoh Satoh · Shin Kurosawa**

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**Abstract**
*Background* Low fraction of inspired oxygen ($F_IO_2$) reduces the atelectasis area during anesthesia induction. However, atelectasis may occur during laryngoscopy and endotracheal intubation because lungs can collapse within a fraction of a second. We assessed the effects of ventilation with 100 and 40 % oxygen on functional residual capacity (FRC) in patients undergoing general anesthesia.
*Methods* Twenty patients scheduled for elective open abdominal surgery were randomized into 40 % oxygen (GI, $n = 10$) and 100 % oxygen (GII, $n = 10$) groups and FRC was measured. Preoxygenation and mask ventilation with 40 and 100 % oxygen were used in GI and GII, respectively. In both groups, 40 % oxygen was used for anesthesia maintenance after intubation. Bilateral lung ventilation was performed with volume guarantee and low tidal volume (7 ml/kg predicted body weight) using bilevel airway pressure. We measured FRC and blood gas in all patients during preoxygenation, after intubation, and during surgery.
*Results* FRC decreased from during preoxygenation (GI 2380 ml, GII 2313 ml) to after intubation (GI 1569 ml, GII 1586 ml) and significantly decreased during surgery (GI 1338 ml, GII 1417 ml) ($P < 0.05$). $PaO_2/F_IO_2$ decreased from during preoxygenation (GI 419 mmHg, GII 427 mmHg) to after intubation (GI 381 mmHg, GII 351 mmHg) and significantly decreased during surgery (GI 333 mmHg, GII 291 mmHg) ($P < 0.05$). No significant differences were found between the groups in both parameters.
*Conclusions* FRC significantly decreased from the awake state to surgery in both groups. FRC was not influenced by $F_IO_2$ elevation at anesthesia induction.

**Keywords** Functional residual capacity · Absorption atelectasis · Oxygen concentration

## Introduction

Absorption atelectasis may occur with the use of high oxygen concentrations during preoxygenation, induction, and maintenance of general anesthesia [1]. This has been shown by chest computed tomography [1, 2]. However, preoxygenation using 100 % oxygen and replacement of all alveolar nitrogen with oxygen are advantageous when mask ventilation and intubation difficulties occur during induction of general anesthesia. Clinically, preoxygenation is considered adequate when the end-tidal oxygen ($F_{ET}O_2$) concentration is >90 %, and the techniques of tidal volume breathing for 3 min or taking 8 deep breaths in 60 s are recommended [3]. Thus, the use of high oxygen concentrations is very important for increased patient safety.

The oxygen reserve in the lung and the safe duration of apnea depend on functional residual capacity (FRC), which is an important parameter in general anesthesia. The FRC is reduced by approximately 20 % (0.4–0.7 l) by several factors in general anesthesia [4, 5]. Some of the mechanisms that reduce FRC are the immediate loss of

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A. Kanaya (✉) · S. Kurosawa
Department of Anesthesiology and Intensive Care, Tohoku University Hospital, 1-1 Seiryomachi, Aoba-ku, Sendai 980-8574, Japan
e-mail: canal_village0207@yahoo.co.jp

D. Satoh
Department of Anesthesiology and Perioperative Medicine, Tohoku University Hospital, Sendai, Japan

inspiratory muscle tone affecting the diaphragm, increased abdominal pressure during the surgical procedure, supine position, infusion solution, and the use of high oxygen concentrations.

We assumed that FRC decreases immediately with the use of high oxygen concentrations after intubation. In this study, we assessed the effects of ventilation with 100 and 40 % oxygen on FRC in patients undergoing general anesthesia.

## Materials and methods

After institutional approval at Tohoku University Hospital, Sendai, Japan, written informed consent was obtained from all patients. Twenty healthy non-smoking patients with American Society of Anesthesiologists physical statuses of class 1 or 2, who underwent elective open abdominal surgery between December 2010 and September 2011, were enrolled in the study. The findings from their electrocardiograms (ECG), chest radiographs, and spirometries were normal.

On arrival at the operating room, all patients rested flat in a supine position on the operating table and were monitored with ECG, non-invasive blood pressure, and pulse oximetry. Before anesthesia induction, radial artery cannulation was performed to measure blood gas. A pressure support level of 2 $cmH_2O$ was added through mask ventilation to measure FRC and blood gas (during preoxygenation) in all patients (*Engström* Carestation™, GE Healthcare UK Ltd., Buckinghamshire, UK). The FRC was defined as face mask FRC concentrations—face mask dead space (100 ml). General anesthesia was induced with fentanyl (1–2 μg/kg) and propofol (target plasma concentration of propofol, 4 μg/ml) using a syringe pump (TCI syringe pump TE-371; Terumo, Tokyo, Japan). To facilitate orotracheal intubation, muscle paralysis was achieved with 0.6 mg/kg rocuronium bromide. As spontaneous breathing ceased, the patients were connected to the breathing circuit using a fitted mask. Bilateral lung ventilation was performed with volume guarantee (pressure-regulated volume control) using bilevel airway pressure, and the upper airway pressure was maintained for 1.3 s. Ventilation was started, and a tidal volume of 7 ml/kg was estimated according to the predicted body weight. The respiratory rate was adjusted to maintain the end-tidal carbon dioxide ($F_{ET}CO_2$) concentration in the expired air at 35–40 mmHg. The predicted body weight was calculated as $45.4 + 0.91 \times$ [height (cm) $- 152.4$] for women or $49.9 + 0.91 \times$ [height (cm) $- 152.4$] for men. After orotracheal intubation, the patients were connected to the breathing circuit without using techniques to reinflate a collapsed lung, including recruitment maneuvers (RMs). We measured FRC and blood gas in all patients 30 min after anesthesia induction (after intubation). Anesthesia was maintained with propofol (target plasma concentration of propofol, 2–4 μg/ml) and remifentanil (0.2–0.3 μg/kg/min) during the examination. The propofol concentration was adjusted to maintain the bispectral index (BIS) at 40–60, as measured using a BIS monitor (A-2000; Aspect Medical Systems, Newton, MA, USA). During anesthesia maintenance, the ventilatory setting was the same as that used during anesthesia induction. Thirty minutes after open abdominal surgery was started, we measured FRC and blood gas (during surgery) in all patients.

The study protocol was based on one used in a previous study [2]. Using a table of random numbers, 20 patients were randomized into two groups: 40 % oxygen (GI, $n = 10$) and 100 % oxygen (GII, $n = 10$). Preoxygenation and mask ventilation with 40 and 100 % oxygen were used in GI and GII, respectively. In both groups, 40 % oxygen was used for anesthesia maintenance after intubation. In both groups, FRC and blood gas (during surgery) were measured until 30 min after open abdominal surgery was started.

The FRC measurements were performed using the *Engström* Carestation™. A modification of the multiple breath nitrogen washout technique was used with a step change of only 10 % in $F_IO_2$ concentration without supplementary tracer gases and interruption of mechanical ventilation [6, 7]. Breath-by-breath inspiratory $CO_2$, $F_IO_2$, $F_{ET}O_2$, and $F_{ET}CO_2$ concentrations were measured using a capnometry, oxygen, volume, gas exchange (COVX) module integrated with a respirator, and the inspiratory $N_2$ ($F_IN_2$) and end-tidal $N_2$ ($F_{ET}N_2$) concentrations were calculated ($F_IN_2 = 1 - F_IO_2$; $F_{ET}N_2 = 1 - F_{ET}O_2 - F_{ET}CO_2$). Breath-by-breath $N_2$ exchange ($N_2$ tidal volume change) was calculated on the basis of inspiratory and expiratory alveolar tidal volumes and $N_2$ concentrations. We then calculated FRC using $N_2$ exchange and $F_IN_2$ and $F_{ET}N_2$ concentrations. This method is based on determination of baseline $O_2$ consumption and $CO_2$ production by indirect calorimetry. When the lung was ventilating with $F_IO_2$ levels of 1.0, the $O_2$ consumption was calculated from the $CO_2$ production with a default respiratory quotient of 0.85, a very high precision of measurements was seen irrespective of the $F_IO_2$ used [6].

### Statistical analysis

Statistical analyses were performed using one-way analysis of variance for repeated measures. A value of $P < 0.05$ was considered statistically significant. Data are displayed as mean ± standard deviation.

The study population was determined on the basis of the following hypothesis. We assumed that FRC of GII decreased 100 ml lower than that of GI and standard deviation 50 ml after intubation. Based on the formula for normal theory and assuming a type I error protection of 0.05 and power of 0.8, 10 patients in each group were required.

## Results

Twenty patients were randomized into GI ($n = 10$) and GII ($n = 10$) groups. No significant differences were observed in the baseline characteristics of study patients between GI and GII (Table 1). All patients were included in the statistical analysis. FRC decreased from during preoxygenation (GI 2380 ml, GII 2313 ml) to after intubation (GI 1569 ml, GII 1586 ml) and significantly decreased to during surgery (GI 1338 ml, GII 1417 ml) ($P < 0.05$). No significant differences in FRC were found between the two groups (Fig. 1). $PaO_2/F_IO_2$ decreased from during preoxygenation (GI 419 mmHg, GII 427 mmHg) to after intubation (GI 381 mmHg, GII 351 mmHg) and significantly decreased during surgery (GI 333 mmHg, GII 291 mmHg) ($P < 0.05$). No significant differences in $PaO_2/F_IO_2$ were found between the two groups (Fig. 2).

Functional residual capacity values were standardized by body weight, because body weight was larger by more than 10 % in Group II than Group I. All FRC values were divided by corresponding body weights to give FRC/kg. No significant differences in FRC/kg were identified between the two groups (Fig. 3).

All patients had $SpO_2$ of >90 % during this study.

**Table 1** Baseline characteristics of study patients

| | GI ($F_IO_2$ 0.4) | GII ($F_IO_2$ 1.0) | *P* value |
|---|---|---|---|
| Age (years) | 56 ± 12 | 63 ± 11 | 0.130 |
| Height (cm) | 156 ± 6 | 157 ± 9 | 0.970 |
| Body weight (kg) | 53 ± 11 | 61 ± 10 | 0.121 |
| Predicted body weight (kg) | 51 ± 5 | 53 ± 8 | 0.908 |
| Body mass index | 22 ± 3 | 24 ± 4 | 0.174 |
| No. of patients | 10 (M2F8) | 10 (M4F6) | 0.329 |

Values are mean ± SD

$$\text{Predicted body weight (kg)} = 45.4 + 0.91 \times (\text{height} - 152.4)\ \text{F}$$
$$49.9 + 0.91 \times (\text{height} - 152.4)\ \text{M}$$

*M* male, *F* female

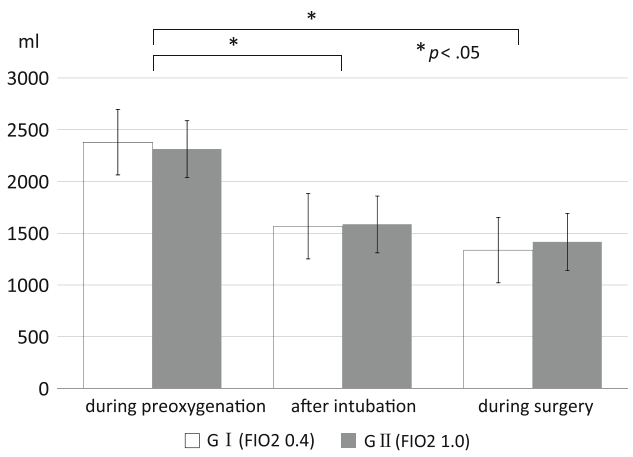


**Fig. 1** Functional residual capacity. Values are mean ± SD. *Asterisks* indicate a statistically significant difference ($P < 0.05$ vs. during preoxygenation)

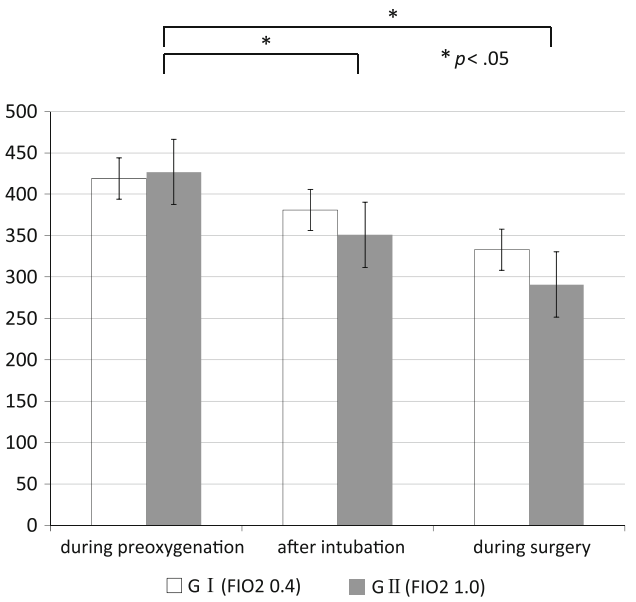


**Fig. 2** $PaO_2/F_IO_2$ ratio. Values are mean ± SD. *Asterisks* indicate a statistically significant difference ($P < 0.05$ vs. during preoxygenation)

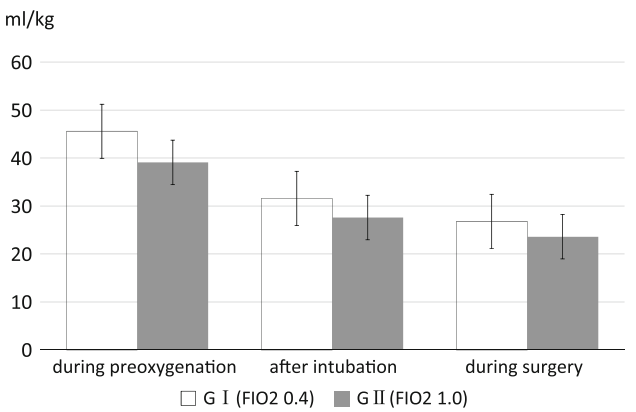


**Fig. 3** Functional residual capacity/body weight. Values are mean ± SD

## Discussion

Our studies have suggested that FRC and $PaO_2/F_IO_2$ during general anesthesia are not influenced by $F_IO_2$ elevation during preoxygenation.

Pulmonary atelectasis occurs in most patients during general anesthesia and is one of the main causes of hypoxemia. In addition, the ventilation to perfusion ratio

($V_A/Q$) declines because of atelectasis. A major cause of atelectasis is the use of high oxygen concentrations. In addition, ventilation with 100 % oxygen may eliminate hypoxic vasoconstriction [1]. Therefore, 100 % oxygen is not always preferable in general anesthesia. In contrast, preoxygenation is considered adequate when $F_{ET}O_2$ concentrations are >90 % [3]. Preoxygenation increases the safe duration of apnea. Edmark et al. [2] found that the intervals between the beginning of apnea and the time for saturation to reach ≤90 % were 411 ± 84, 303 ± 59, and 213 ± 69 s in groups ventilated with 100, 80, and 60 % oxygen, respectively, during induction of general anesthesia. The interval decreases especially in obese patients because of FRC reduction by cephalad diaphragmatic displacement in the supine position. Preoxygenation of obese patients in the 25-degree head-up position or the sitting position is recommended [8]. The FRC is important not only in obese patients but also in non-obese patients because it is the main oxygen store.

In previous studies [4, 5, 9, 10], FRC decreased by approximately 20 % during general anesthesia. However, Satoh et al. [11] showed that FRC decreased by 37 % from the awake level after the induction of anesthesia and these highly significant FRC decreases were similar to ours. In addition, our mean $PaO_2/F_IO_2$ was lower than that was reported in a similar study by Rusca et al. [12]. Their mechanical ventilation provided a tidal volume of 10 ml/kg with PEEP. Thus, lower tidal volume without PEEP in this study may have caused atelectasis. In our study, no significant differences in FRC were found between the 40 and 100 % oxygen inspiration groups. It is possible that 100 % oxygen caused only minor atelectasis, and that this did not influence FRC compared with the use of 40 % oxygen. With respect to the time margin before unacceptable desaturation and FRC in our study, preoxygenation using 100 % oxygen may be more advantageous than that using 40 % oxygen for desaturation and FRC.

Lung RMs and PEEP reduce or prevent atelectasis, thereby improving end-expiratory lung volume, respiratory mechanics, and oxygenation and reducing postoperative lung complications [13–15]. Ventilation of the lungs with pure oxygen after a vital capacity maneuver results in rapid reappearance of atelectasis. But if 40 % $O_2$ in $N_2$ is used for a vital capacity maneuver, atelectasis reappears slowly. Thus, the use of moderate $F_IO_2$ was recommended in RMs by Hedenstierna et al. [16]. In maintenance of general anesthesia, RMs using moderate $F_IO_2$ and sufficient PEEP are important for improving FRC reduction, which occurs during induction of general anesthesia, and maintaining lung function.

In this study, FRC measurements were based on the modified multiple breath nitrogen washout technique using a change in $F_IO_2$ of only 0.1, which is commercially available (*Engström* Carestation™). When lung models were ventilated with $F_IO_2$ of 0.3–0.4, 0.7, and 1.0 using step changes of 0.1 for FRC measurements, very high precision was observed irrespective of $F_IO_2$, and high precision during lung model evaluation and good reproducibility in patients were demonstrated by Olegård [6]. However, a potential limitation of this study is the accuracy of FRC using 100 % oxygen. It has been suggested in the manufacture's specifications that the accuracy error increases from 10 to 15 % at a $F_IO_2$ >65 % [17] and this accuracy error might have an influence on our results.

Functional residual capacity significantly decreased from the awake state to surgery regardless of inspired oxygen at anesthesia induction. Therefore, preoxygenation using 100 % oxygen may be advantageous because of the increased safe duration of apnea. It is important to improve the unavoidable FRC reduction that occurs during general anesthesia using RMs and sufficient PEEP.

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