The effect of the fraction of inspired oxygen during alveolar recruitment on absorption atelectasis in laparoscopic surgery: A randomized, controlled trial

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Abstract

Background

The intraoperative alveolar recruitment maneuver (ARM) efficiently treats atelectasis, but the effect of Fio₂ during ARM on atelectasis is uncertain. Here, we investigated this effect.

Methods

Patients undergoing elective laparoscopic surgery in the Trendelenburg position were randomized to low- (Fio₂ 0.4; n = 44) and high-Fio₂ (Fio₂ 1.0, n = 46) groups. ARMs were performed 1-min post tracheal intubation and post changes between supine and Trendelenburg positions during surgery. Intraoperative Fio₂ was set at 0.4 for both groups. Modified lung ultrasound (LUS) scores were calculated to assess lung aeration after inducing anesthesia and at surgery completion. The primary outcome was modified LUS score at the end of the surgery, and secondary outcomes were the intra- and postoperative Pao₂ to Fio₂ ratio and postoperative pulmonary complications.

Results

Both groups presented similar modified LUS scores before capnoperitoneum and ARM (P = 0.747). However, the postoperative modified LUS score was significantly lower in the low- than in the high-Fio₂ group (7.0 ± 4.1 vs 11.7 ± 4.2, mean difference 4.7, 95% CI 2.96–6.44, P < 0.001). Significant atelectasis postoperatively was more common in the high-Fio₂ group (relative risk 1.77, 95% CI 1.27–2.47, P < 0.001). Intra- and postoperative Pao₂ to Fio₂ were similar and no postoperative pulmonary complications occurred. Atelectasis occurred more frequently when ARM was performed with high than with low Fio₂. High-Fio₂ did not benefit oxygenation.

Conclusions

In patients undergoing laparoscopic surgery in the Trendelenburg position, absorption atelectasis occurred more frequently when the ARM was performed with high rather than low Fio₂. No oxygenation benefit was observed in the high-Fio₂ group.

Trial registration:

ClinicalTrials.gov, NCT03943433. Registered 7 May 2019, https://clinicaltrials.gov/ct2/show/NCT03943433

Background

During general anesthesia, atelectasis reportedly occurs in most patients (1), typically due to absorption atelectasis, compression of the lung tissue, and impairment of surfactant function (2). Additionally, for laparoscopic surgeries, the increased abdominal pressure of capnoperitoneum may shift the diaphragm cranially and decrease respiratory compliance (3, 4). Moreover, the steep Trendelenburg position used in laparoscopic gynecologic or colon surgeries further aggravates lung collapse and decreases functional residual capacity (5, 6).

Intraoperative atelectasis is associated with decreased lung compliance, impaired oxygenation, increased pulmonary vascular resistance, and lung injury (5, 7). Moreover, atelectasis can persist postoperatively, resulting in respiratory complications, such as hypoxemia and infection, which may significantly impact patient recovery (5, 8).

The alveolar recruitment maneuver (ARM) with positive-end expiratory pressure (PEEP) is widely accepted as an efficient for atelectasis treatment (9–11). Although demonstrated to be effective ARM (9, 10, 12, 13), reports on
the impact of Fio₂ during ARM on atelectasis development are rare, and have not limited Fio₂ to the ARM per se. While ARM with high Fio₂ can improve oxygenation rapidly, there is a greater possibility of absorption atelectasis occurring.

Lung ultrasound (LUS) is a non-invasive, radiation-free, and portable diagnostic modality (14, 15). Recent studies have also reported on LUS utility in the operating room (14–18). The diagnostic reliability of LUS for detecting perioperative atelectasis has been verified against computed tomography or magnetic resonance imaging (14, 18).

We prospectively assessed the impact of Fio₂, specifically during ARM, on atelectasis development, by means of LUS. We hypothesized that during the ARM, a high Fio₂ (1.0) would lead to a higher degree of postoperative atelectasis, without benefiting oxygenation, than low Fio₂ (0.4).

**Methods**

**Design**

This prospective, patient- and sonographer-blinded, single-center, randomized, controlled trial was approved by the Institutional Review Board of Seoul National University Hospital (No. 1903-137-1020, 22 April 2019) and registered at ClinicalTrials.gov (NCT03943433, 7 May 2019). The study was conducted in accordance with CONSORT guidelines. After obtaining written informed consent, we enrolled 98 adult patients scheduled to undergo elective laparoscopic gynecologic surgery or colorectal surgery in the Trendelenburg position from May to November 2019. Adult patients aged 20–70 years, with American Society of Anesthesiologists physical status I–III, were included. We excluded patients with cardiovascular impairment, severe chronic obstructive pulmonary disease (preoperative forced expiratory volume in 1 second/forced vital capacity of 60% or lower) or emphysema, pneumothorax or bullae, previous lung resection surgery, and increased intracranial pressure. Patients dropped-out in cases of protocol violation, massive bleeding with hemodynamic compromise, or unexpected open conversion.

Patients were randomly assigned to either of 2 groups according to the applied Fio₂ during ARM, in a 1:1 ratio, by computer-generated randomization, using R software (version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria). Allocation was concealed in an opaque envelope by an assistant not involved in the study and was delivered to the attending anesthesiologist before general anesthesia induction. The sonographer (BRK or HB) was completely blinded to the group assignment.

**Anesthesia and ventilator strategy**

General anesthesia was induced according to the predetermined protocol with standard monitoring of pulse oximetry (Spo₂), non-invasive blood pressure, electrocardiography, bispectral index (A-2000 XP; Aspect Medical Systems, Newton, MA), and end-tidal carbon dioxide concentration. After preoxygenation with 100% oxygen, propofol 1.5–2.0 mg kg⁻¹ was administered intravenously along with target-controlled continuous remifentanil infusion (Orchestra; Fresenius Kabi, Brézins, France). Rocuronium 0.6–0.8 mg kg⁻¹ was administered for neuromuscular blockade and tracheal intubation was performed. General anesthesia was maintained with sevoflurane and remifentanil to maintain the bispectral index within 40–60. A radial arterial catheter was placed, connected to an arterial waveform analysis system (Flotrac; Edwards Lifesciences, Irvine, CA), to monitor continuous arterial blood pressure and cardiac output.

Mechanical ventilation was maintained intraoperatively with Fio₂ at 0.4, tidal volume at 8 ml kg⁻¹ of ideal body weight, PEEP at 5 cmH₂O, inspiration to expiration ratio of 1:2, and end-inspiration pause 10% at volume-controlled ventilation mode. Respiratory rate was adjusted to maintain partial pressure of arterial carbon dioxide at 35–45 mmHg. In case peak airway pressure exceeded 35 cmH₂O, tidal volume was decreased stepwise by 1 ml kg⁻¹ until the peak pressure was < 35 cmH₂O.
At the end of the surgery, sugammadex 2–4 mg kg\(^{-1}\) was administered after train-of-four count monitoring for reversal of neuromuscular block. Fio\(_2\) was changed to 1.0 when the first spontaneous breathing was observed. After extubation, patients were transferred to the post-anesthesia care unit (PACU). Intravenous patient-controlled analgesia was routinely used for postoperative pain control. Patients were discharged from the PACU when they met the Modified Aldrete Score criteria (19).

**LUS examination and ARM strategy**

LUS was performed at 3 time-points: 1 minute after starting mechanical ventilation, at the end of surgery (before emergence), and 30 minutes after PACU admission (Fig. 1). LUS was conducted by 2 investigators (BRK and HB) who were blinded to group assignment. Both investigators had experience of more than 100 cases of LUS examination. LUS was performed in the supine position using a Vivid-I ultrasound device (GE Healthcare, Chalfont St. Giles, Bucks, UK) and a convex probe, with a frequency of 2.5 MHz–7.5 MHz. All intercostal spaces were examined as previously described: each hemithorax was divided into 6 regions with 3 longitudinal lines (parasternal, anterior, and posterior axillary) and 2 axial lines (one above the diaphragm and another at 1 cm above the nipples) (14). Each region was scored according to the modified LUS system suggested by Monastesse and others, which showed sufficient sensitivity to detect loss of aeration in laparoscopic surgery (20). The degree of aeration was rated from 0 to 3 as follows: 0, 0–2 B lines; 1, ≥ 3 B lines or 1 or multiple subpleural consolidations separated by a normal pleural line; 2, multiple coalescent B lines or multiple subpleural consolidations separated by a thickened or irregular pleural line; 3, consolidation or small subpleural consolidation exceeding 1 × 2 cm in diameter (20). The points for the 12 regions were summed for analysis. Furthermore, we defined significant atelectasis as when a score of 2 or 3 was assigned in any region.

ARMs were performed after LUS examinations (twice) under real-time LUS guidance, with the probe placed at the region with the highest score. After setting the Fio\(_2\) (1.0 or 0.4) according to the assignment, continuous positive airway pressure was applied from 15 cmH\(_2\)O in 5-cmH\(_2\)O stepwise increments, up to the pressure at which no collapsed area was observed. The applied pressure (opening pressure) and the duration of the ARM were recorded. Additional intraoperative ARM were performed at several time points; at Trendelenburg positioning and at every 30 minutes thereafter, as well as when the position was returned to supine after the main procedure was finished. Intraoperative ARM were performed with the initially recorded pressure and duration after adjustment of Fio\(_2\) according to group assignment. The pre-designated Fio\(_2\) was applied only during the ARM, after which it reverted to and was maintained at 0.4 throughout mechanical ventilation in both groups.

**Outcomes**

The primary outcome was the modified LUS score at surgery completion (before emergence), reflecting aeration loss developed during general anesthesia. The secondary outcomes were the modified LUS score at PACU arrival, significant atelectasis observed by LUS, the intraoperative Pa\(_{O2}\) to Fio\(_2\) ratio, the postoperative Pa\(_{O2}\) to Fio\(_2\) ratio, the incidence of intraoperative desaturation (Spo\(_2\) < 95%), the incidence of postoperative fever (body temperature ≥ 37.5 °C during hospital stay), and the incidence of postoperative pulmonary complications during hospital stay. Arterial blood samples were obtained at 20 minutes after changing between the supine and Trendelenburg positions and at arrival in the PACU. Postoperative pulmonary complications included respiratory infection, respiratory failure, pleural effusion, atelectasis, pneumothorax, bronchospasm, and aspiration pneumonitis, according to a previous study by Gallart and others (21). Additionally, data on age, height, weight, sex, type of operation, duration of anesthesia and surgery, the pressure and duration of the ARM, and ventilator parameters were collected. Significant hemodynamic deterioration during the ARM (> 20% of baseline) was documented and treated with vasoactive drugs or crystalloid agents.

**Statistical Analysis**

In a previous pilot study, with patients undergoing laparoscopic surgery in the Trendelenburg position, the modified LUS scores [mean (SD)] before and at the end of surgery were 3.88 (1.26) and 8.66 (2.82). Considering a 20% decrease in the modified LUS score in the high Fio\(_2\) group, we calculated that 44 patients would be needed in each group, with a type-I error risk of 0.05 and a power of 0.8 for two-tailed analysis.
Continuous variables were summarized as mean (SD) or median (interquartile range), and were analyzed with unpaired or paired t-tests and the Mann–Whitney U or Wilcoxon signed-rank tests, after assessing the normality of data distribution with the Shapiro–Wilk test. The number of patients (%) was compared with the chi-squared test or Fisher’s exact test. Statistical analyses were performed with R software (version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria). In all analyses, $P$-values < 0.05 were regarded as statistically significant.

Results

One-hundred-and-seventy-eight patients who were scheduled to undergo laparoscopic surgery in the Trendelenburg position were assessed for eligibility. Among them, 98 patients met the inclusion criteria and were randomized to the low- ($n = 49$) or the high-$\text{FiO}_2$ group ($n = 49$). Five patients in the low-$\text{FiO}_2$ and 2 patients in the high-$\text{FiO}_2$ group dropped out due to an intraoperative position change to supine, and 1 patient was excluded due to breakdown of the ultrasound machine. Consequently, 44 and 46 patients in each group were analyzed (Fig. 2).

Subjects’ baseline characteristics are summarized in Table 1. The 2 groups did not differ in terms of patient characteristics or operational data. Modified LUS scores are presented in Table 2. The baseline modified LUS score, measured at 1 minute after anesthesia induction did not differ between the 2 groups ($P = 0.747$; Table 2). For the primary outcome, the modified LUS score at the end of surgery was significantly lower in the low-$\text{FiO}_2$ than in the high-$\text{FiO}_2$ group (mean difference 4.7, 95%CI 2.96–6.44, $P < 0.001$; Table 2). Moreover, the modified LUS score at 30 minutes after PACU admission was significantly lower in the low-$\text{FiO}_2$ than in the high-$\text{FiO}_2$ group ($P < 0.001$; Table 2). Significant atelectasis at 1 minute after starting mechanical ventilation was observed in 12 (27.3%) and 15 (32.6%) patients in the low- and high-$\text{FiO}_2$ groups, respectively ($P = 0.747$). However, this was more frequently observed in the high-$\text{FiO}_2$ than in the low-$\text{FiO}_2$ group after surgery completion (relative risk 1.77, 95%CI 1.27–2.47, $P < 0.001$; Table 2) and at PACU arrival (relative risk 1.73, 95%CI 1.26–2.38, $P < 0.001$; Table 2).

The perioperative $\text{Pao}_2$ to $\text{FiO}_2$ ratio did not differ between the low- and high-$\text{FiO}_2$ groups at any of the time-points (Table 3). The incidence of intraoperative desaturation was similar between the 2 groups ($P = 0.959$; Table 4), and the lowest $\text{Spo}_2$ value during anesthesia also did not differ between the groups ($P = 0.119$; Table 4). Hemodynamic and respiratory variables while in the Trendelenburg position with capnoperitoneum are summarized in Table 4.

The opening pressure used for the ARM varied from 25 to 40 cmH$_2$O and was similar between groups ($P = 0.773$). For 38 patients in the low-$\text{FiO}_2$ group (86.4%) and 40 patients in the high-$\text{FiO}_2$ group (87.0), 30 cmH$_2$O was used to resolve atelectasis. An opening pressure of 35 cmH$_2$O was required for 4 (9.1%) and for 5 (10.9%) patients in the low-$\text{FiO}_2$ and high-$\text{FiO}_2$ group, respectively; an opening pressure of 25 cmH$_2$O was required for 1 patient in each group. One patient in the low-$\text{FiO}_2$ group required the use of 40 cmH$_2$O pressure to restore all collapsed areas. Hemodynamic deterioration was observed in 21 (47.7%) and 20 (43.5%) patients during ARM in the low- and high-$\text{FiO}_2$ group, respectively ($P = 0.687$).

No postoperative pulmonary complication was reported during hospital stay in any of the participants (Table 4). Five (9.1%) and 3 (6.5%) patients showed subsegmental atelectasis on postoperative chest X-ray in the low- and high-$\text{FiO}_2$ group, respectively ($P = 0.710$; Table 4). Postoperative fever ($\geq 37.5^\circ\text{C}$) occurred in 55.6% of the study population, but the incidence was similar between the low- and high-$\text{FiO}_2$ groups ($P = 0.602$; Table 4).

Discussion

This study evaluated the impact of $\text{FiO}_2$ during the ARM on postoperative atelectasis development, using LUS. The postoperative modified LUS score was higher in the high-$\text{FiO}_2$ group than in the low-$\text{FiO}_2$ group, indicating
more severe loss of aeration. In addition, postoperative consolidation was more frequently observed in the high-Fio\textsubscript{2} group, while no significant difference was observed in preoperative modified LUS score. In terms of oxygenation, there was no significant difference between groups at any time-point. These observations were consistent with our hypothesis that, using high Fio\textsubscript{2} (1.0) during the ARM would not benefit oxygenation and would cause more postoperative atelectasis than using low Fio\textsubscript{2} (0.4).

High Fio\textsubscript{2} has been considered responsible for development of absorption atelectasis during general anesthesia (22, 23). To the best of our knowledge, however, the impact of high Fio\textsubscript{2} temporarily applied during ARMs on atelectasis development has not been investigated previously. In the present study, patients assigned to the high-Fio\textsubscript{2} group received ARM with Fio\textsubscript{2} 1.0, whereas those in the low-Fio\textsubscript{2} group received ARM with Fio\textsubscript{2} 0.4. The Fio\textsubscript{2} was uniformly maintained at 0.4 with 5-cmH\textsubscript{2}O PEEP during post-ARM mechanical ventilation in both groups. A high oxygen concentration in the alveoli during ARM was predicted to cause more absorption atelectasis. Consequently, the postoperative modified LUS score was markedly better in the low-Fio\textsubscript{2} than in the high-Fio\textsubscript{2} group and the difference persisted in the PACU.

Rothen and others demonstrated the progression of absorption atelectasis over time, using computed tomography, after ARMs in 12 patients, using Fio\textsubscript{2} of 0.4 or 1.0 during ARM and thereafter (24). While absorption atelectasis developed within 5 minutes in the Fio\textsubscript{2} 1.0 group, it developed after 40 minutes in the Fio\textsubscript{2} 0.4 group. Although the impact of oxygen concentration was obvious, this previous and the present study differed in that the previous study applied the designated Fio\textsubscript{2} not only during ARM, but also during the rest of the study period. Additionally, Song and colleagues studied absorption atelectasis according to Fio\textsubscript{2} during mechanical ventilation was evaluated by LUS in children (25). Although Fio\textsubscript{2} had no impact on the incidence of significant atelectasis (consolidation score ≥ 2), high Fio\textsubscript{2} caused higher consolidation and B-line scores. That study compared Fio\textsubscript{2} 0.3 and 0.6, which is a relatively small difference, and did not included laparoscopic surgeries in the Trendelenburg position, which may explain the discrepancy with our results.

We observed no significant difference in the Pa\textsubscript{o2} to Fio\textsubscript{2} ratio at any time point. Recruitment of collapsed alveoli with high oxygen concentrations led to a rapid re-collapse of the inflated alveoli, rather than benefiting oxygenation. In clinical practice, Fio\textsubscript{2} may be raised during the ARM to improve Spo\textsubscript{2} immediately, in case of desaturation during surgery. Nonetheless, we found that high Fio\textsubscript{2} during ARM does not actually improve oxygenation, despite a transient, rapid increase in Spo\textsubscript{2}. A recent study of 32 patients undergoing laparoscopic cholecystectomy compared Pa\textsubscript{o2} levels after 2 intraoperative ARMs, with Fio\textsubscript{2} 0.3 or Fio\textsubscript{2} 1.0 (26). Intraoperative Pa\textsubscript{o2} did not differ between the 2 groups, but Pa\textsubscript{o2} was significantly better in the Fio\textsubscript{2} 0.3 group, by postoperative blood gas analysis, which differed from our findings. This may be due to differences in mean operation time and position between the studies. Atelectasis may be more affected by Fio\textsubscript{2} than by other factors in surgery using a sitting position, such as laparoscopic cholecystectomy than in surgery using a Trendelenburg position.

The overall intraoperative desaturation incidence was markedly lower in our study than in the study of Monastesse and others, which was assumed to be mainly due to repetitive ARMs [defined as Spo\textsubscript{2} < 95% vs. Spo\textsubscript{2} < 94%; 5/90 (5.6%) vs. 4/29 (13.8%); excluding a case of endobronchial intubation] (20). Spo\textsubscript{2} never fell below 90% in either group in our study and no patients required rescue by a change in Fio\textsubscript{2} or PEEP. Furthermore, in-hospital pulmonary complications were absent in both groups. Inclusion of only patients with low risk of pulmonary complications may account for this complication-free recovery in pulmonary function, along with repeated ARMs during mechanical ventilation. Postoperative fever (≥ 37.5°C) developed in a considerable number of patients in both groups. Length of hospital stay was non-significantly longer in the high-Fio\textsubscript{2} group.

The postoperative modified LUS scores in the present study were in accordance with those of Monastesse and colleagues (20). The PACU score of the low-Fio\textsubscript{2} group was lower and that of the high-Fio\textsubscript{2} group was higher than in the previous study, although the mean values of both studies were similar. We also analyzed the incidence of significant atelectasis additionally; it was observed in > 80% of patients in the high-Fio\textsubscript{2} group. A higher score as
well as consolidation were mainly observed in the posterior (dependent) part of the thorax. This high significant atelectasis incidence may be attributed to pneumoperitoneum and the Trendelenburg position. As all patients showed at least a single, small, subpleural consolidation after pneumoperitoneum in Monastesse and colleagues’ study (20), the incidence of significant atelectasis is likely to be acceptable. Nonetheless, the significant atelectasis observed in our study did not alter the clinical outcome.

Our study had several limitations. Firstly, since only patients with a low risk of pulmonary complications were included, our results may not extend to patients with lung disease. Moreover, clinical consequences of the observed atelectasis may not have been observed for the same reason. Second, the anesthesiologist who performed the ARM was not blinded. However, the anesthesiologist performing LUS for outcome measurement was blinded to the Fio₂ used for the ARM. Third, there is a possibility of incomplete intraoperative recruitment with the opening pressure obtained in the supine state before surgical incision. The opening pressure was used since access to the dependent part of the thorax was limited during the surgery. Nevertheless, it was considered to be sufficiently effective because ARMs were mostly performed at a high pressure of ≥ 30 cmH₂O. Fourth, the definition of significant atelectasis was not validated by previous studies. Although previous literature have used LUS as a diagnostic tool for atelectasis (14, 18, 20, 27–29), criteria for significant atelectasis need to be established.

In conclusion, for patients undergoing laparoscopic surgery in the Trendelenburg position, absorption atelectasis occurred more frequently when ARMs were performed with high Fio₂ than when it was performed with low Fio₂. Based on the findings of our study, high Fio₂ during the ARM yields no oxygenation benefit and may result in more atelectasis than low Fio₂.

Abbreviations

Alveolar recruitment maneuver, ARM; positive-end expiratory pressure, PEEP; Lung ultrasound, LUS; post-anesthesia care unit, PACU

Declarations

Ethics approval and consent to participate

This trial was approved by the Institutional Review Board of Seoul National University Hospital (No. 1903-137-1020, 22 April 2019) and written informed consent was obtained from all participants.

Consent for publication: Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions

Study design: BRK, J-HB, SY

Study conduct and data collection: BRK, SL, HB, ML
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Table

Table 1. Characteristics of patients, surgery, and anesthesia
|                          | Low-Fio<sub>2</sub> group (n=44) |
|--------------------------|----------------------------------|
| Age (year)               | 49.5 (43.0–59.0)                 |
| Female, n                | 32 (72.7)                        |
| Height (cm)              | 158.5 (154.7–165.5)              |
| Weight (kg)              | 61.7 (54.0–68.9)                 |
| Predicted body weight (kg)| 52.0 (48.0–59.5)                 |
| Body mass index (kg m<sup>2</sup>) | 23.7 (21.8–26.2)          |
| ASA classification (I/II), n | 31/13                              |

**Comorbidity**

- Hypertension, n | 9 (20.5)
- Diabetes mellitus, n | 3 (6.8)
- Current Smoker, n | 4 (9.1)

**ARISCAT score** | 23 (8–26)

**Type of surgery**

- Laparoscopic colorectal surgery, n | 21 (47.7)
- Laparoscopic gynecologic surgery, n | 23 (52.3)

**Operative profiles**

- Duration of anesthesia (min) | 147.5 (107.5–195.5)
- Duration of surgery (min) | 100.0 (70.0–140.0)
- Duration of Trendelenburg position (min) | 70.0 (46.5–100.5)
- Intraoperative crystalloid administration (ml) | 600.0 (500.0–875.0)
- Estimated blood loss (ml) | 65.0 (40.0–112.5)
- Urine output (ml) | 130.0 (80.0–200.0) (n=39)*
- Intraoperative inotropic requirement, n | 20.0 (45.4)
Values are expressed as median (Interquartile range) or number (%). ASA, American Society of Anesthesiologists; ARISCAT, Assess Respiratory Risk in Surgical patients in Catalonia. *Urine output was measured in patients with Foley catheter.

Table 2. Intraoperative and postoperative modified lung ultrasound scores

|                                | Low-Fio2 group |
|--------------------------------|---------------|
|                                | (n=44)        |

**Baseline, after intubation**

|                                |               |
|--------------------------------|---------------|
| Significant atelectasis, n     | 12 (27.3)     |
| Total modified LUS score       | 5.0 (3.0–8.0) |
| Anterior regions               | 0.0 (0.0–1.0) |
| Lateral regions                | 1.0 (0.0–2.5) |
| Posterior regions              | 4.0 (2.0–4.0) |

**End of surgery, before extubation**

|                                |               |
|--------------------------------|---------------|
| Significant atelectasis, n     | 21 (47.7)     |
| Total modified LUS score       | 7.0 (4.1)     |
| Anterior regions               | 0.0 (0.0–2.0) |
| Lateral regions                | 1.5 (0.0–2.5) |
| Posterior regions              | 4.0 (3.0–6.0) |

**Post-anesthesia care unit, before discharge**

|                                |               |
|--------------------------------|---------------|
| Significant atelectasis, n     | 22 (50.0)     |
| Total modified LUS score       | 8.0 (4.6)     |
| Anterior regions               | 1.0 (0.0–2.5) |
| Lateral regions                | 2.2 (1.8)     |
| Posterior regions              | 4.0 (3.0–6.0) |

Data are expressed as mean (standard deviation), median (interquartile range), or number (%). Anterior, lateral, and posterior regions of the thorax were divided by the anterior and posterior axillary lines. LUS, lung ultrasound.
Table 3. Perioperative \( \text{Pao}_2 \) to \( \text{Fio}_2 \) ratio from arterial blood gas analysis

|                          | Low-\( \text{Fio}_2 \) group |
|--------------------------|--------------------------------|
|                          | (\( n=44 \))                  |
| Baseline, preoperative   | 430.0 (385.0–492.5)            |
| Intraoperative           |                                |
| 20 min after induction   | 490.0 (410.0–531.2)            |
| 20 min after Trendelenburg | 405.0 (111.4)                  |
| 20 min after supine      | 471.8 (117.4)                  |
| Post-anesthesia care unit, postoperative | 457.5 (397.5–552.5) |

Data are expressed as mean (standard deviation) or median (Interquartile range).

Table 4. Intraoperative and postoperative variables
Hemodynamic variables during anesthesia

| Variable                                           | Value               |
|----------------------------------------------------|---------------------|
| Heart rate (beats min\(^{-1}\))                   | 62.2 (57.0–67.4)    |
| Mean arterial pressure (mmHg)                      | 88.8 (9.3)          |
| Cardiac index (L min\(^{-1}\) m\(^{-2}\))         | 2.5 (2.2–3.3)       |
| Stroke volume variation (%)                        | 9.5 (3.9)           |
| Mean Spo\(_2\) (%)                                | 99.9 (99.5–100.0)   |
| Lowest Spo\(_2\) (%)                              | 99.0 (98.0–100.0)   |
| Intraoperative desaturation (Spo\(_2\)<95%), n     | 3 (6.8)             |

Respiratory parameters during capnoperitoneum

| Variable                                           | Value               |
|----------------------------------------------------|---------------------|
| Minute ventilation (L min\(^{-1}\))                | 6.3 (0.9)           |
| Peak inspiratory pressure (cmH\(_2\)O)             | 23.8 (3.6)          |
| Static compliance (ml cmH\(_2\)O\(^{-1}\))         | 29.7 (7.8)          |

Postoperative outcome variables

| Variable                                           | Value               |
|----------------------------------------------------|---------------------|
| Fever within postoperative 24 hours (≥37.5°C), n    | 23 (52.3)           |
| Atelectasis on postoperative chest X-ray, n         | 4 (9.1)             |
| Length of hospital stay (day)                      | 3.5 (2.0–5.0)       |
| In-hospital pulmonary complication, n              | 0 (0.0)             |

Data are expressed as mean (standard deviation), median (interquartile range), or number (%).
Figure 1

Experimental protocol during general anesthesia. GA, general anesthesia; PACU, post-anesthesia care unit; LUS, lung ultrasound; ABGA, arterial blood gas analysis.
Randomized (n=98)

Allocation

Low-Fio2 (0.4) group (n=49)
- Received allocated intervention (n=49)
- Did not receive allocated intervention (n=0)

Follow-Up

- Lost to follow up (n=0)
- Discontinued intervention
  Operation proceeded in supine position (n=5)

Analysis

Analyzed (n=44)
- Excluded from analysis (n=0)
Figure 2

CONSORT diagram. COPD, chronic obstructive pulmonary disease; ASA, American Society of Anesthesiologists.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CONSORT2010Checklist.doc