Lung ultrasound score to determine the effect of fraction 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 (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.

Background

During general anesthesia, atelectasis reportedly occurs in most patients (1), typically due to absorption of gas, compression of the lung tissue, and impairment of surfactant function (2). Additionally, during laparoscopic surgery, the increased abdominal pressure of capnoperitoneum may shift the diaphragm cranially and decrease respiratory compliance (3, 4). Compression of basal lung regions due to a stiffened diaphragm would accelerate the formation of atelectasis that was already initiated during anesthesia induction (4). Moreover, the steep Trendelenburg position used in laparoscopic gynecologic or colon surgery causes the abdominal contents to push the diaphragm more cephalad, resulting in aggravated lung collapse and decreased 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 and result in respiratory complications, such as hypoxemia and infection, significantly impacting patient recovery (5, 8).

The alveolar recruitment maneuver (RM) with positive-end expiratory pressure (PEEP) is widely accepted as efficient for atelectasis treatment (9-11). Although demonstrated to be effective RM (9, 10, 12, 13), reports on the impact of Fio\textsubscript{2} during RM on atelectasis development are rare, and have not limited Fio\textsubscript{2} to the RM per se (14). While RM with high Fio\textsubscript{2} can improve oxygenation rapidly, there is a greater possibility of absorption atelectasis occurring.

Lung ultrasound is non-invasive, radiation-free, and portable (15, 16), and recent studies have shown the utility of the lung ultrasound score (LUSS) in the operating room (15-19). The diagnostic reliability of LUSS for detecting perioperative atelectasis has been verified against computed tomography or magnetic resonance imaging (15, 19).

We prospectively assessed the impact of Fio\textsubscript{2}, specifically during RM, on atelectasis development, using the LUSS. We hypothesized that during RM, a high Fio\textsubscript{2} (1.0) leads to a higher risk for postoperative atelectasis in adults undergoing laparoscopic surgery, without benefiting oxygenation, than low Fio\textsubscript{2} (0.4).

**Methods**

**Design**

This prospective, patient- and sonographer-blinded, single-center, parallel, 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. We enrolled adult patients scheduled to undergo elective laparoscopic gynecologic surgery or colorectal surgery in the Trendelenburg position from May to November 2019 after obtaining written informed consent. The inclusion criterion was adult patients aged 20–70 years with an American Society of Anesthesiologists physical status I–II. The exclusion criteria were patients with body mass index $\geq 35$ kg m$^{-2}$, 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. Some patients dropped out because of protocol violation, massive bleeding with hemodynamic compromise, or unexpected open conversion.

Patients were randomly assigned to two groups based on the applied Fio\textsubscript{2} during RM, 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 ($\text{Spo}_2$), 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 with a continuous target-controlled 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 sevourane and remifentanil to maintain the bispectral index within 40–60. A radial arterial catheter was placed and connected to an arterial waveform analysis system (Flotrac; Edwards Lifesciences, Irvine, CA) to monitor continuous arterial blood pressure and the cardiac output.

Mechanical ventilation was maintained intraoperatively with the $\text{Fio}_2$ at 0.4, tidal volume at 8 ml kg$^{-1}$ of ideal body weight, PEEP at 5 cmH$_2$O, 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. If the peak airway pressure exceeded 35 cmH$_2$O, the tidal volume was decreased stepwise by 1 ml kg$^{-1}$ until the peak pressure was <35 cmH$_2$O.

At the end of the surgery, sugammadex 2–4 mg kg$^{-1}$ was administered after train-of-four count monitoring for reversal of neuromuscular blockade. The $\text{Fio}_2$ 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 (20).

**Lung ultrasound examination and RM strategy**

Lung ultrasound examination was performed at three time-points: 1 minute after starting mechanical ventilation, at the end of surgery (before emergence), and after breathing room air for 20 minutes at PACU (Figure 1). Lung ultrasound was performed by two investigators (BRK and HB) blinded to the group assignment. Both investigators had performed more than 100 cases of lung ultrasound. The ultrasound 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 six regions with three longitudinal lines (parasternal, anterior, and posterior axillary) and two axial lines (one above the diaphragm and another at 1 cm above the nipples) (15). Each region was scored according to the modified LUSS system suggested by Monastesse et al., which showed sufficient sensitivity to detect loss of aeration during laparoscopic surgery (21). The degree of deaeration was rated from 0 to 3 as follows (Figure 2): 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; and 3, consolidation or small subpleural consolidation exceeding 1×2 cm in diameter (21). The points for the 12 regions were summed for analysis. Furthermore, we defined significant atelectasis as a score of 2 or 3 assigned to any region.

RMs were performed after lung ultrasound examinations (twice) under real-time ultrasound guidance, with the probe placed at the region with the highest score. After setting the Fio₂ (1.0 or 0.4) according to the assignment, continuous positive airway pressure was applied from 15 cmH₂O in 5-cmH₂O stepwise increments, up to the pressure at which no collapsed area was observed. The maximum continuous airway pressure applied during RM was 40 cmH₂O. The applied pressure (opening pressure) and the duration of the RM were recorded. Additional intraoperative RMs were performed at several time-points: at the time of Trendelenburg positioning and at every 30 minutes thereafter, and after a return to supine position after procedure completion (Figure 1). Intraoperative RMs were performed using the initial pressure and duration after adjustment of Fio₂ according to the group assignment. The pre-designated Fio₂ was applied only during the RM, after which it was maintained at 0.4 throughout mechanical ventilation in both groups.

Outcomes

The primary outcome was the modified LUSS at surgery completion (before emergence), reflecting an aeration loss during general anesthesia. The secondary outcomes were the modified LUSS at PACU, significant atelectasis observed on lung ultrasound, intraoperative and postoperative Pao₂/Fio₂ ratios, and incidences of intraoperative desaturation (Spo₂ <95%), postoperative fever (body temperature ≥38°C during hospital stay), and postoperative pulmonary complications during hospital stay. Arterial blood samples were obtained 20 minutes after a change in position from supine to Trendelenburg and after breathing room air for 20 minutes at the PACU. Postoperative atelectasis, pneumonia, acute respiratory distress syndrome, and pulmonary aspiration data were collected by reviewing medical records. Their severity was evaluated based on previous consensus definitions for standardized perioperative pulmonary complications (22). In our study, in-hospital pulmonary complications were atelectasis, pneumonia, acute respiratory distress syndrome and mild-to-severe pulmonary aspiration. Data on postoperative pulmonary complications were collected during the hospital stay. Additionally, data on age, height, weight, sex, type of operation, duration of anesthesia and surgery, pressure and duration of RM, and ventilator parameters were collected. Significant hemodynamic deterioration during RM (>20% of baseline) was documented and treated with vasoactive drugs or crystalloid agents.

Statistical analysis

In our pilot study on patients undergoing laparoscopic surgery in the Trendelenburg position (n=10), the modified LUSS [mean (SD)] before and at the end of surgery were 3.88 (1.26) and 8.66 (2.82), respectively. Considering a 20% decrease in the modified LUSS in the low Fio₂ 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). The variables were analyzed using 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. Number of patients (%) was compared using 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). For all analyses, $P<0.05$ was statistically significant.

Results

One-hundred-and-seventy-eight patients 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-Fio$_2$ groups ($n=49$). Five patients in the low-Fio$_2$ and two patients in the high-Fio$_2$ group dropped out owing to an intraoperative change to supine position. One patient was excluded owing to an ultrasound machine breakdown. Consequently, 44 and 46 patients in each group were analyzed, respectively (Figure 3).

Participants’ baseline characteristics are summarized in Table 1. The groups did not differ in terms of patient characteristics or operational data. The modified LUSS are presented in Table 2. The baseline modified LUSS, measured at 1 minute after anesthesia induction did not differ between the groups ($P=0.747$). For the primary outcome, the modified LUSS at the end of surgery was significantly lower in the low-Fio$_2$ group (median difference 5.0, 95% CI 3.0–7.0, $P<0.001$). Moreover, the modified LUSS at 20 minutes after breathing room air at the PACU was significantly lower in the low-Fio$_2$ group ($P<0.001$). 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-Fio$_2$ groups, respectively ($P=0.747$). However, this was more frequently observed in the high-Fio$_2$ after surgery completion (relative risk 1.77, 95% CI 1.27–2.47, $P<0.001$) and at PACU (relative risk 1.73, 95% CI 1.26–2.38, $P<0.001$).

The perioperative Pao$_2$ to Fio$_2$ ratio did not differ between the groups at any time-point (Table 3). The incidence of intraoperative desaturation and the lowest Spo$_2$ value during anesthesia did not differ between the groups ($P=0.959$ and $P=0.119$, respectively) (Table 4). Hemodynamic and respiratory variables in the Trendelenburg position with capnoperitoneum are summarized in Table 4.

The opening pressure for the RM varied from 25 to 40 cmH$_2$O and was similar between groups ($P=0.773$). For 38 patients in the low-Fio$_2$ group (86.4%) and 40 patients in the high-Fio$_2$ group (87.0), 30 cmH$_2$O was used to resolve the atelectasis. An opening pressure of 35 cmH$_2$O was needed for four (9.1%) and for five (10.9%) patients in the low-Fio$_2$ and high-Fio$_2$ groups, respectively. For one patient in each group, an opening pressure of 25 cmH$_2$O was required. One patient in the low-Fio$_2$ group required 40 cmH$_2$O to
restore all collapsed areas. Hemodynamic deterioration was observed in 21 (47.7%) and 20 (43.5%) patients during RM in the low- and high-Fio\textsubscript{2} groups, respectively (P=0.687).

No postoperative pulmonary complication was reported during hospital stay. (Table 4). Five (9.1%) and 3 (6.5%) patients showed subsegmental atelectasis on postoperative radiographs in the low- and high-Fio\textsubscript{2} groups, respectively (P=0.710). Postoperative fever (≥38°C) occurred in 55.6% of the study population, with a similar incidence between the 2 groups (P=0.602).

**Discussion**

This study evaluated the impact of Fio\textsubscript{2} during RM on development of postoperative atelectasis, using lung ultrasound. The postoperative modified LUSS was higher in the high-Fio\textsubscript{2} group, indicating more severe aeration loss in this group. In addition, postoperative consolidation was more frequently observed in the high-Fio\textsubscript{2} group, with no significant difference in the preoperative modified LUSS. Oxygenation was similar between groups at any time-point. These observations were consistent with our hypothesis that using a high Fio\textsubscript{2} (1.0) during RM would not benefit oxygenation and lead to more postoperative atelectasis than using a low Fio\textsubscript{2} (0.4).

High Fio\textsubscript{2} is associated with the development of absorption atelectasis during general anesthesia (23, 24). However, to the best of our knowledge, the impact of a temporary high Fio\textsubscript{2} during RMs on atelectasis development has not been investigated. In this study, patients assigned to the high-Fio\textsubscript{2} group received RM with Fio\textsubscript{2} 1.0, whereas those in the low-Fio\textsubscript{2} group received RM 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-RM mechanical ventilation in both groups. A high oxygen concentration in the alveoli during RM was predicted to cause increased absorption atelectasis. Consequently, the postoperative modified LUSS was significantly lower in the low-Fio\textsubscript{2}, with the difference persisting in the PACU.

Using computed tomography, Rothen et al. demonstrated the progression of absorption atelectasis over time after RMs in 12 patients, with an Fio\textsubscript{2} of 0.4 or 1.0 during RM and thereafter (25). Absorption atelectasis developed within 5 minutes in the Fio\textsubscript{2} 1.0 group and after 40 minutes in the Fio\textsubscript{2} 0.4 group. Although the impact of oxygen concentration was obvious, this and the present study differed in that the previous study applied the designated Fio\textsubscript{2} not only during RM, but also during the rest of the study period. Additionally, Song et al. studied absorption atelectasis based on the Fio\textsubscript{2} during mechanical ventilation, using lung ultrasound in children (14). Although the Fio\textsubscript{2} had no significant impact on the incidence of significant atelectasis (consolidation score≥2), a high Fio\textsubscript{2} led to higher consolidation and B-line scores. The study compared Fio\textsubscript{2} of 0.3 and 0.6, which is a relatively small difference, and did not include laparoscopic surgeries in the Trendelenburg position, which may explain its discrepancy with our results.
We observed no significant difference in the $P_{aO_2}$ to $F_{iO_2}$ ratio at any time-point. Recruitment of collapsed alveoli with high oxygen concentrations led to a rapid re-collapse of the inflated alveoli than benefiting oxygenation. In clinical practice, $F_{iO_2}$ may be increased during RM for rapid improvements in $Spo_2$, in cases of desaturation during surgery. Nonetheless, we found that a high $F_{iO_2}$ during RM did not actually improve oxygenation, despite a transient, rapid increase in $Spo_2$. A recent study of 32 patients undergoing laparoscopic cholecystectomy compared $P_{aO_2}$ levels after two intraoperative RMs, with $F_{iO_2}$ 0.3 and $F_{iO_2}$ 1.0 (26). Although the intraoperative $P_{aO_2}$ did not differ between the groups, it was significantly better in the $F_{iO_2}$ 0.3 group on postoperative blood gas analysis. This finding differed from that in our study because of possible differences in the mean operation time and the patients’ position. During surgery in a sitting position, such as laparoscopic cholecystectomy, the atelectasis may be more affected by $F_{iO_2}$ than other factors, compared to in surgery performed in a Trendelenburg position.

In our study, the overall intraoperative desaturation incidence was markedly lower than that in the study of Monastesse et al.; this could be mainly due to repetitive RMs [defined as $Spo_2 < 95\%$ vs. $Spo_2 < 94\%; 5/90$ (5.6\%) vs. $4/29$ (13.8\%), excluding a case of endobronchial intubation] (21). In our study, the $Spo_2$ did not decrease below 90\% in either group, and no patient required a rescue by a change in the $F_{iO_2}$ or PEEP. Furthermore, in-hospital pulmonary complications were absent in both groups. This may have been due to the inclusion of only patients with a low risk of pulmonary complications, along with repeated RMs during mechanical ventilation. Postoperative fever ($\geq 38^\circ{C}$) developed in a considerable number of patients in both groups. The length of hospital stay was non-significantly longer in the high-$F_{iO_2}$ group.

The postoperative modified LUSS in this study was similar to that in the study by Monastesse et al (21). In our study, the PACU score in the low-$F_{iO_2}$ group was lower and that of the high-$F_{iO_2}$ group was higher than in the previous study, although the mean values in both studies were similar. We also analyzed the incidence of significant atelectasis, which was observed in $>80\%$ of patients in the high-$F_{iO_2}$ group. A higher score and consolidation were mainly observed in the posterior (dependent) part of the thorax, which can be attributed to pneumoperitoneum and the Trendelenburg position. As all patients showed at least a single, small, subpleural consolidation after pneumoperitoneum in the study of Monastesse et al. (21), this 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. First, ultrasound is an operator-dependent imaging modality (27), and observed findings may vary based on the operator's experience. However, the sonographers in our study were well-experienced in lung ultrasound examination, and therefore, operator-related variations were minimal. Second, since only patients with a low risk of pulmonary complications were included; therefore, our results cannot be extended to patients with lung disease. Moreover, clinical consequences of the atelectasis may not have been observed for the same reason. Third, the anesthesiologist who performed the RM was not blinded. However, the anesthesiologist performing lung ultrasound for outcome measurement was blinded to the $F_{iO_2}$ used for the RM. Fourth, 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 as access to the dependent part of the thorax was limited during the surgery. Nevertheless, it was considered to be sufficiently effective because RM's were mostly performed at a high pressure of $\geq 30$ cmH$_2$O. Fifth, we applied uniform PEEP of 5 cmH$_2$O to all patients, not an individualized PEEP. After open up the lung with RM, sufficient level of PEEP is required to keep the lung free of collapse. However, identifying the optimal PEEP is another topic that should be further discussed. Lastly, the definition of significant atelectasis was not validated by previous studies. Although previous studies have used lung ultrasound as a diagnostic tool for atelectasis (15, 19, 21, 28-30), the criteria for significant atelectasis are yet to be established.

In conclusion, for patients undergoing laparoscopic surgery in the Trendelenburg position, a higher LUSS, reflecting a higher degree of absorption atelectasis, was observed when RM's were performed with a high Fio$_2$ (1.0) than with a low Fio$_2$ (0.4). We also found that using a high Fio$_2$ during RM yields no oxygenation benefit and may result in more atelectasis than when using low Fio$_2$.

**Abbreviations**

Recruitment maneuver, RM; positive-end expiratory pressure, PEEP; Lung ultrasound score, LUSS; 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

Data analysis: ML, SL, SY
Acknowledgements: Not applicable

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Tables

Table 1. Characteristics of patients, surgery, and anesthesia
|                          | Low-Fio\textsubscript{2} group (n=44) | High-Fio\textsubscript{2} group (n=46) | \(P\)-value |
|--------------------------|---------------------------------------|----------------------------------------|-------------|
| Age (year)               | 49.5 (43.0–59.0)                      | 54.5 (43.0–61.0)                       | 0.508       |
| Female, n                | 32 (72.7)                             | 28 (60.9)                              | 0.332       |
| Height (cm)              | 158.5 (154.7–165.5)                   | 161.4 (156.0–170.0)                    | 0.184       |
| Weight (kg)              | 61.7 (54.0–68.9)                      | 60.5 (54.0–70.0)                       | 0.987       |
| Predicted body weight (kg)| 52.0 (48.0–59.5)                      | 54.0 (48.0–66.0)                       | 0.140       |
| Body mass index (kg m\textsuperscript{2}) | 23.7 (21.8–26.2)                      | 24.1 (21.0–25.9)                       | 0.617       |
| ASA classification (I/II), n | 31/13                                 | 24/22                                  | 0.118       |

**Comorbidity**

|                          | Low-Fio\textsubscript{2} group (n=44) | High-Fio\textsubscript{2} group (n=46) | \(P\)-value |
|--------------------------|---------------------------------------|----------------------------------------|-------------|
| Hypertension, n          | 9 (20.5)                              | 11 (23.9)                              | 0.888       |
| Diabetes mellitus, n     | 3 (6.8)                               | 7 (15.2)                               | 0.351       |
| Current Smoker, n        | 4 (9.1)                               | 7 (15.2)                               | 0.572       |
| ARISCAT score            | 23 (8–26)                             | 19 (7–26)                              | 0.322       |
| ARISCAT low/intermediate risk, n | 31/13                                 | 26/20                                  | 0.249       |

**Type of surgery**

|                          | Low-Fio\textsubscript{2} group (n=44) | High-Fio\textsubscript{2} group (n=46) | \(P\)-value |
|--------------------------|---------------------------------------|----------------------------------------|-------------|
| Laparoscopic colorectal surgery, n | 21 (47.7)                              | 27 (58.7)                              |             |
| Laparoscopic gynecologic surgery , n | 23 (52.3)                              | 19 (41.3)                              |             |

**Operative profiles**

|                          | Low-Fio\textsubscript{2} group (n=44) | High-Fio\textsubscript{2} group (n=46) | \(P\)-value |
|--------------------------|---------------------------------------|----------------------------------------|-------------|
| Duration of anesthesia (min) | 147.5 (107.5–195.5)                    | 170.0 (115.0–230.0)                    | 0.109       |
| Duration of surgery (min)  | 100.0 (70.0–140.0)                     | 125.0 (85.0–180.0)                     | 0.058       |
| Duration of Trendelenburg position (min) | 70.0 (46.5–100.5)                     | 80.0 (56.0–142.0)                     | 0.054       |
| Intraoperative crystalloid administration (ml) | 600.0 (500.0–875.0)                    | 700.0 (400.0–1000.0)                   | 0.484       |
Estimated blood loss (ml)  65.0 (40.0–112.5)  100.0 (50.0–200.0)  0.145

Urine output (ml)  130.0 (80.0–200.0) (n=39)*  150.0 (85.0–265.0) (n=43)*  0.111

Intraoperative inotropic requirement, n  20.0 (45.4)  28.0 (60.9)  0.356

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-Fio\textsubscript{2} group (n=44) | High-Fio\textsubscript{2} group (n=46) | \(P\)-value |
|-----------------------------------|--------------------------------------|---------------------------------------|--------------|
| **Baseline, after intubation**    |                                      |                                       |              |
| Significant atelectasis, \(n\)   | 12 (27.3)                            | 15 (32.6)                             | 0.747        |
| Total modified LUSS               | 5.0 (3.0–8.0)                        | 4.0 (4.0–6.0)                        | 0.524        |
| Anterior regions                  | 0.0 (0.0–1.0)                        | 0.0 (0.0–1.0)                        | 0.538        |
| Lateral regions                   | 1.0 (0.0–2.5)                        | 1.0 (0.0–2.0)                        | 0.427        |
| Posterior regions                 | 4.0 (2.0–4.0)                        | 3.0 (3.0–4.0)                        | 0.839        |
| **End of surgery, before extubation** |                                    |                                       |              |
| Significant atelectasis, \(n\)   | 21 (47.7)                            | 39 (84.8)                             | <0.001       |
| Total modified LUSS               | 6.0 (4.5–9.0)                        | 12.0 (9.0–14.0)                      | <0.001       |
| Anterior regions                  | 0.0 (0.0–2.0)                        | 2.0 (1.0–4.0)                        | <0.001       |
| Lateral regions                   | 1.5 (0.0–2.5)                        | 3.5 (2.0–4.0)                        | <0.001       |
| Posterior regions                 | 4.0 (3.0–6.0)                        | 6.0 (5.0–8.0)                        | <0.001       |
| **Post-anesthesia care unit, before discharge** | |                                       |              |
| Significant atelectasis, \(n\)   | 22 (50.0)                            | 40 (87.0)                             | <0.001       |
| Total modified LUSS               | 7.0 (5.0–10.0)                       | 12.0 (10.0–16.0)                     | <0.001       |
| Anterior regions                  | 1.0 (0.0–2.5)                        | 3.0 (2.0–4.0)                        | <0.001       |
| Lateral regions                   | 2.0 (1.0–3.5)                        | 4.0 (2.0–5.0)                        | <0.001       |
| Posterior regions                 | 4.0 (3.0–6.0)                        | 7.0 (5.0–8.0)                        | <0.001       |

Data are expressed as median (interquartile range), or number (%). Anterior, lateral, and posterior regions of the thorax were divided by the anterior and posterior axillary lines. LUSS, lung ultrasound score.

**Table 3.** Perioperative \(\text{Pao}_2\) to \(\text{Fio}_2\) ratio from arterial blood gas analysis
|                                | Low-Fio₂ group  | High-Fio₂ group | \( P \)-value |
|--------------------------------|-----------------|-----------------|---------------|
| **Baseline, preoperative**     | 430.0 (385.0–492.5) | 438.0 (370.0–485.0) | 0.422         |
| **Intraoperative**             |                 |                 |               |
| 20 min after induction         | 490.0 (410.0–531.2) | 437.5 (375.0–530.0) | 0.364         |
| 20 min after Trendelenburg     | 405.0 (111.4)   | 408.6 (123.5)   | 0.884         |
| 20 min after supine           | 471.8 (117.4)   | 490.8 (142.2)   | 0.492         |
| Post-anesthesia care unit, postoperative | 457.5 (397.5–552.5) | 455.0 (400.0–495.0) | 0.448         |

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

**Table 4.** Intraoperative and postoperative variables
| Hemodynamic variables during anesthesia | Low-Fio<sub>2</sub> group (n=44) | High-Fio<sub>2</sub> group (n=46) | P-value |
|----------------------------------------|---------------------------------|---------------------------------|---------|
| Heart rate (beats min<sup>-1</sup>)     | 62.2 (57.0–67.4)                | 62.5 (57.8–70.3)                | 0.214   |
| Mean arterial pressure (mmHg)           | 88.8 (9.3)                      | 87.8 (7.8)                      | 0.586   |
| Cardiac index (L min<sup>-1</sup> m<sup>-2</sup>) | 2.5 (2.2–3.3)                   | 2.5 (2.1–3.0)                   | 0.457   |
| Stroke volume variation (%)             | 9.5 (3.9)                       | 10.8 (3.6)                      | 0.103   |
| Mean Spo<sub>2</sub> (%)                | 99.9 (99.5–100.0)               | 99.8 (99.1–100.0)               | 0.154   |
| Lowest Spo<sub>2</sub> (%)              | 99.0 (98.0–100.0)               | 98.0 (97.0–100.0)               | 0.119   |
| Intraoperative desaturation (Spo<sub>2</sub>&lt;95%), n | 3 (6.8)                         | 2 (4.3)                         | 0.959   |

| Respiratory parameters during capnoperitoneum | Low-Fio<sub>2</sub> group (n=44) | High-Fio<sub>2</sub> group (n=46) | P-value |
|-----------------------------------------------|---------------------------------|---------------------------------|---------|
| Minute ventilation (L min<sup>-1</sup>)       | 6.3 (0.9)                       | 6.4 (1.0)                       | 0.563   |
| Peak inspiratory pressure (cmH<sub>2</sub>O)  | 23.8 (3.6)                      | 23.3 (3.1)                      | 0.485   |
| Static compliance (ml cmH<sub>2</sub>O<sup>-1</sup>) | 29.7 (7.8)                     | 30.1 (7.3)                      | 0.776   |

| Postoperative outcome variables | Low-Fio<sub>2</sub> group (n=44) | High-Fio<sub>2</sub> group (n=46) | P-value |
|---------------------------------|---------------------------------|---------------------------------|---------|
| Fever within postoperative 24 hours (&gt;38.0°C), n | 6 (13.6)                       | 10 (21.7)                       | 0.317   |
| Atelectasis on postoperative chest X-ray, n | 4 (9.1)                       | 3 (6.5)                         | 0.710   |
| Length of hospital stay (day)    | 3.5 (2.0–5.0)                   | 5.0 (2.0–6.0)                   | 0.096   |
| In-hospital pulmonary             | 0 (0.0)                        | 0 (0.0)                         |         |
complication, n

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

Figures
| Event                           | Assigned Fio₂ | Recruitment Maneuver | LUSS ABGA              |
|--------------------------------|---------------|----------------------|------------------------|
| Preoperation                   |               |                      |                        |
| Preoxygenation                 |               |                      | **ABGA (#1)**          |
| Tracheal intubation            | 0.4           |                      | **LUSS (#1)**          |
| Trendelenburg position + Pneumoperitonium | 0.4         | **US guided RM (#1)** | **ABGA (#2)** 20 min after RM |
| Operative procedure            | 0.4           | **RM**               | **ABGA (#3)** 20 min after RM |
| Supine position                | 0.4           | **RM**               | **ABGA (#4)** 20 min after RM |
| End of surgery                 | 0.4           |                      | **LUSS (#2)**          |
| Extubation                     | 1.0           |                      |                        |
Figure 1

Experimental protocol during general anesthesia. GA, general anesthesia; PACU, post-anesthesia care unit; LUSS, lung ultrasound score; ABGA, arterial blood gas analysis
Figure 2

Lung ultrasound findings with different scores. Modified lung ultrasound scoring system in accordance with the method of Monastesse et al. (A) Normal pattern ‘bat-sign’ with A-lines parallel to the pleural line, score=0; (B) More than three B lines arising from pleural line, score=1; (C) Multiple subpleural consolidations separated by an irregular pleural line, score=2; (D) Large-sized consolidation, score=3. Each arrow indicates pathologic findings of each figure.
Figure 3

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

Supplementary Files

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