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Lung ultrasound score-based assessment of postoperative atelectasis in obese patients according to inspired oxygen concentration

A prospective, randomized-controlled study

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Abstract

Background: According to a recent meta-analysis, in patients with a body mass index (BMI) ≥ 30, a high fraction of inhaled oxygen (FiO_2) did not increase postoperative atelectasis. However, a high FiO_2 generally increases the risk of postoperative atelectasis. Therefore, this study aimed to evaluate the effect of FiO_2 on the development of atelectasis in obese patients using the modified lung ultrasound score (LUSS).

Methods: Patients were assigned to 4 groups: BMI ≥ 30: group A (n = 21) and group B (n = 20) and normal BMI: group C (n = 22) and group D (n = 21). Groups A and C were administered 100% O_2 during preinduction and emergence and 50% O_2 during anesthesia. Groups B and D received 40% O_2 for anesthesia. The modified LUSS was assessed before and 20 min after arrival to the postanesthesia care unit (PACU).

Results: The difference between the modified LUSS preinduction and PACU was significantly higher in group A with a BMI ≥ 30 (*P* = .006); however, there was an insignificant difference between groups C and D in the normal BMI group (*P* = .076).

Conclusion: High FiO_2 had a greater effect on the development of atelectasis in obese patients than did low FiO_2; however, in normal-weight individuals, FiO_2 did not have a significant effect on postoperative atelectasis.

Abbreviations: ABGA = arterial blood gas analysis, BMI = body mass index, CT = computed tomography, FiO_2 = fraction of inspired oxygen, LUSS = lung ultrasound score, PACU = postanesthesia care unit, PaO_2 = arterial partial pressure of oxygen, PEEP = positive end-expiratory pressure, SpO_2 = oxygen saturation by pulse oximeter.

Keywords: atelectasis, lung ultrasound score, obese

1. Introduction

Most anesthesiologists administer a high fraction of inspired oxygen (FiO_2) during induction and emergence of anesthesia to prevent desaturation, in preparation for unpredictable difficult intubation,[1–3] ventilation failure, and loss of airway patency,[4] especially in obese patients.[5] Unfortunately, administration of a high intraoperative inspired oxygen concentration can lead to postoperative pulmonary complications.[6] One of the most common and serious postoperative respiratory complications on the first day after surgery is atelectasis[7,8] which arouses ventilation/perfusion mismatch,[9] consequently interrupting oxygenation of blood.[10] For this reason, efforts to reduce the inhaled oxygen concentration during anesthesia are increasing.[6,11]

Contrary to the fact that obese patients are more prone to atelectasis due to decreased functional residual capacity,[12–14] many recent studies have shown that the rate of atelectasis in obese patients does not increase significantly even if a high inhaled oxygen concentration is administered.[15–17] The increase in body mass index (BMI) promotes cyclic airway closure, which in turn interferes with preoxygenation and alveolar ventilation, resulting in nitrogen retention. It can be explained that these alveoli are resistant to atelectasis, preventing atelectasis formation during preoxygenation and ventilator-assisted anesthesia.[16] However, this meta-analysis did not consider the degree of atelectasis of the obese patient prior to anesthesia, and the various durations of exposure to different

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

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concentrations of oxygen and various types of surgeries were included.[12,13,15–17]

Therefore, this study was designed to target patients undergoing surgery that does not affect lung dynamics, to avoid exposure to high concentrations of oxygen even for a short period of time in the group receiving a low FiO_2, and to examine the effect of inhaled oxygen concentration on the development of atelectasis by differentiating obese and normal-weight patients.

Previous research[12,15,16,18,19] on factors affecting the formation of atelectasis have evaluated atelectasis using computed tomography (CT), which is considered the gold standard for lung imaging. It is unsuitable for a regular examination of perioperative atelectasis because of the inconvenience and risk of radiation exposure. However, lung ultrasound is a portable, noninvasive, and radiation-free device.[20] Recent studies have shown the diagnostic accuracy of the lung ultrasound score (LUSS) for detecting perioperative atelectasis using CT or magnetic resonance imaging.[21,22]

Few attempts have been made toward LUSS-based assessment of postoperative atelectasis formation and the effectiveness of low inspired oxygen concentrations in obese patients. Therefore, we prospectively assessed postoperative atelectasis formation and the impact of applying a low inspired oxygen fraction in obese and normal-weight patients using lung ultrasound.

2. Materials and Methods

2.1. Design

This study was a multicenter prospective randomized controlled trial conducted at the Korea University Ansan Hospital and Korea University Anam Hospital from March 2021 to December 2021. After receiving approval from the Korea University Institutional Review Board (2020AS0333 and 2021AN0038), written informed consent was obtained from all subjects participating in the study. The trial was registered prior to subject enrollment in the Clinical Research Information Service (https://cris.nih.go.kr, KCT0007081, Registered on March 13, 2022, principal investigator: Yoon Ji Choi).

This study was conducted in accordance with the consolidated standards of reporting trials (CONSORT) guidelines. All patients were enrolled from the Department of Orthopedic Surgery, Korea University Ansan and Anam Hospital, by the research staff. After providing an explanation of the trial, written informed consent was obtained from all participants the day before the surgery. The current study was conducted in accordance with ethical principles of the Declaration of Helsinki.

2.2. Inclusion and exclusion criteria

This trial was performed on 96 patients, with 24 patients per group. Inclusion criteria included patients who were aged 20 to 80 years, had an American Society of Anesthesiologists physical status I to III, and were scheduled for upper extremity or lower extremity surgery requiring arterial line placement under general anesthesia. The exclusion criteria included patients with acute respiratory disease, mental retardation or severe cognitive impairment, history of a previous intrathoracic procedure, cardiopulmonary compromised status, or intraoperative schedule other than supine position were excluded from the study. Patients who refused to participate in the study and incurred protocol violation, unexpectedly changed position, or manifested intraoperative decrease in oxygen saturation by pulse oximeter (SpO_2) below 94% were also excluded.

Patient data were divided into 2 groups (BMI ≥ 30 and normal BMI groups). The BMI ≥ 30 group was subdivided into groups A (high FiO_2, n = 21) and B (low FiO_2, n = 20), and the BMI normal group was further subdivided into groups C (high FiO_2, n = 22) and D (low FiO_2, n = 21).

A single investigator was responsible for the group assignment of patients. Randomization was performed using a web-based computer-generated list (www.randomization.com). The assigned groups were kept in opaque sealed envelopes that were opened before induction in the operating room by an independent anesthesiologist who was not involved in the study. Neither the patients nor the lung ultrasound estimator were aware of the concentration of inspired oxygen.

2.3. Anesthetic protocol

General anesthesia was induced according to a predetermined protocol with standard monitoring of pulse oximetry, noninvasive blood pressure, electrocardiography, bispectral index (A-2000 XP; Aspect Medical Systems, Newton, MA), and end-tidal carbon dioxide concentration (GE Datex-Ohmeda Aestiva 3000; GE Healthcare, Wauwatosa, WI).

After preoxygenation with 100% O_2 for groups A and C and with 40% O_2 for groups B and D, anesthesia induction was achieved using propofol 2 mg/kg, remifentanil, and rocuronium 0.6 mg/kg. Patients in groups A and C were ventilated using a mask with desflurane and 100% oxygen for 2 minutes 30 seconds, followed by intubation (7.5–8.0 for males and 6.5–7.0 for females using a Portex tracheal tube). Patients in groups B and D were ventilated using a mask with desflurane and 40% oxygen for 2 minutes 30 seconds followed by intubation. Mechanical ventilation was maintained at a tidal volume of 8 mL/kg of ideal body weight, 1:2 of inspiration-to expiration ratio, and ventilation frequency (10–16 per minute of respiratory rate) was adjusted to maintain end-tidal carbon dioxide at 30 to 35 mm Hg. The setting of positive end-expiratory pressure (PEEP) was left to the independent anesthesiologist in charge of surgery to set it autonomously. The pressure limit of the peak inspiratory pressure was 35 mm Hg. For groups A and C, anesthesia was maintained with desflurane inhalation in 50% oxygen at a fresh gas flow of 3.0 L/min to achieve a bispectral index within 40 to 60 and by continuous remifentanil intravenous infusion for a mean arterial pressure of 65 to 95 mm Hg and a heart rate of 80–100 beats per minute. For groups B and D, the anesthetic settings during maintenance were the same, except that the inspired oxygen fraction was adjusted to 40%. After tracheal intubation was completed, radial artery catheterization was performed using Allen's test. At the end of the surgery, the administration of desflurane and remifentanil was discontinued, fresh gas flow was increased to 8 L/min of oxygen, and sugammadex 2 mg/kg was administered after train-of-four count monitoring for reversal of neuromuscular blockade. Groups B and D maintained an inhaled oxygen concentration of 40% during emergence. Whenever any patient suffered hypoxia (SpO_2 <94%) using a pulse oximeter, 100% oxygen was administered as necessary to patients in either group to maintain oxygenation, and patients were excluded from the study. Patients in groups A and C used 100% O_2 during emergence. After recovery of spontaneous breathing and consciousness, extubation was performed and the patient was transferred to the postanesthesia care unit (PACU). Patients were routinely administered O_2 3 L via nasal prong for 20 minutes and discontinued if their SpO_2 remained above 94%. Patients were discharged from the PACU when they satisfied the modified Aldrete score criteria.

2.4. Lung ultrasound examination

Lung ultrasound examination was performed before induction and 20 minutes after arrival to the PACU. Lung ultrasound was performed by 2 investigators blinded to the group assignment. Ultrasonography was performed in the supine position using a Sonosite Edge ultrasound system (Fuji Film, Bothell, WA) and a linear probe with a frequency of 6 to 12 MHz. Patients were scanned in the supine position following the lung ultrasound examination method described by Monastesse and colleagues.[23] The thorax was divided by the anterior axillary line, the posterior axillary line, and a horizontal line beneath the nipple. The intercostal spaces of each of the 12 areas were scanned and analyzed. Aeration loss was assessed by calculating the modified LUSS, which showed sufficient sensitivity to detect aeration loss. Two lung ultrasound examiners provided scores for each area after simultaneous examination of the lung scan. The LUSS of the thorax (0–36) was then calculated by summing the scores of the 12 individual quadrants, with higher scores indicating more severe aeration loss. The degree of deaeration was rated from 0 to 3 as follows: 0, 0 to 2 B lines; ≥3 B lines or 1 or multiple subpleural consolidations separated by a normal pleural line; multiple coalescent B lines or multiple subpleural consolidations separated by a thickened or irregular pleural line; and consolidation or small subpleural consolidation exceeding 1 cm × 2 cm in diameter.[23]

2.5. Outcomes

The primary outcome was the difference in value between the preinduction period modified LUSS and PACU period modified LUSS, reflecting aeration loss after general anesthesia. The secondary outcomes were modified LUSS at each period, intraoperative and first day after surgery arterial partial pressure of oxygen (PaO_2) to FiO_2 ratios, incidence of intraoperative desaturation (SpO_2 <94%), postoperative fever (body temperature > 37.5 °C during hospital stay), and postoperative pulmonary complications during hospital stay. In our study, in-hospital pulmonary complications included clinical diagnoses of atelectasis, pneumonia, radiological abnormalities such as pneumothorax, pulmonary congestion, pleural effusion, atelectasis, and prolonged oxygen therapy (>1 day after the end of surgery) for respiratory insufficiency, acute respiratory distress syndrome, and mild-to-severe pulmonary aspiration.[24]

Arterial blood samples were obtained 20 minutes after initiation of mechanical ventilation and 1 day after surgery. Chest radiography (anteroposterior views) was performed before surgery with routine preoperative investigations and on the first postoperative day, with patients in a semi-sitting position. Postoperative atelectasis, pneumonia, acute respiratory distress syndrome, and pulmonary aspiration data were collected by reviewing medical records. Data on postoperative pulmonary complications were collected during the hospital stay. Additionally, data on age, height, weight, sex, comorbidities including hypertension, diabetes, cardiac disease, cerebrovascular disease, renal disease, type of operation, ventilator parameters at the beginning and end of surgery, length of hospital stay after surgery, and perioperative outcomes including duration of anesthesia and surgery, amount of transfusion and colloid use, total fluid, blood loss, and urine output were collected.

2.6. Statistical analysis

To estimate the sample size, a power analysis revealed that 19 patients in each of the 4 groups were required at a power of 0.8, an $\alpha = 0.05$, and effect size = 0.39 (obtained from preliminary results), considering our primary outcome. The present study required 114 participants to allow for a 50% dropout rate.

Continuous variables were summarized as mean ± standard deviation, median (interquartile range), or number (%). 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 using the Shapiro–Wilk test. The number of patients (%) was compared using the chi-squared test or Fisher's exact test. To determine whether the LUSS difference value was associated with age, sex, PEEP, and operation time, univariable and multivariable linear regression analyses were performed. The statistical result of this analysis was expressed as a coefficient, ß, and *P* values. Data were analyzed using SPSS version 21 (SPSS Inc., Chicago, IL). Statistical significance was set a *P* value less than 0.05.

3. Results

A total of 57 patients were divided into 2 groups (BMI ≥ 30 group and normal BMI group), as shown in Figure 1. Among them, 11 patients in the BMI ≥ 30 group and 10 in the normal BMI group were excluded after enrollment. Seven patients (one in group A, 4 in group B, 1 in group C, and 1 in group D) were excluded because they could not be followed up with the lung ultrasound owing to urgent operating room-related work of doctors performing lung ultrasound. The study proceeded well according to the study protocol, except for 2 patients in the normal BMI group (one in group C and 1 in group D) whose FiO_2 was accidentally changed.

The baseline characteristics of the participants are summarized in Table 1. There were no differences in most patient characteristics: Group A had more renal disease than group B in the BMI ≥ 30 group (*P* = .048), and group D had significantly more angina than group C in the normal BMI group (*P* = .049).

The modified LUSS values are presented in Table 2. The baseline modified LUSS measured before induction did not differ between groups. In the subgroups of the BMI ≥ 30 group, there were no statistically significant differences in LUSS values measured before induction and in the PACU. However, there were significantly higher LUSS differences in the anterior (*P* = .033) and posterior regions (*P* = .014) of the thorax in group A using high FiO_2 than in group B. The total modified LUSS values also differed between the subgroups (*P* = .006) in the BMI ≥ 30 group. In the subgroups of the normal BMI group, the modified LUSS value of the posterior region performed in the PACU was significantly higher in group C using a high FiO_2 (*P* = .032). However, there were no statistically significant differences in LUSS between subgroups. There was no difference in the number of patients who received PEEP between each group, and PEEP was set at 5 cmH_2O.

There was no significant difference in the PaO_2 to FiO_2 ratio between the groups during surgery and on the first postoperative day (Table 3). In addition, there was no significant difference between preoperative basal SpO_2 value, postoperative PACU SpO_2 value, and perioperative desaturation event.

As shown in Table 4, there were no differences in fever within 24 hours postoperatively, atelectasis, pulmonary congestion, or pneumonia on postoperative chest radiography and in-hospital pulmonary complications between subgroups of BMI ≥ 30 and the normal BMI group. The length of hospital stay was not significantly different in the subgroups of the BMI ≥ 30 group, but in the subgroups of the normal BMI group, group C using a high FiO_2 had a longer (*P* = .040) length of hospital stay than group D using low FiO_2.

Univariate and multivariate linear regression analyses were used to identify factors that significantly influenced the LUSS difference value in Table 5. Typical factors associated with the LUSS difference value were analyzed using univariate analysis, and multivariate analysis was performed using 4 factors with a *P* value < .2. Only PEEP significantly reduced the LUSS difference value in the group with a BMI ≥ 30 and the group with a normal BMI ($\beta = -2.443$, *P* = .022 for BMI ≥ 30 group, $\beta = -2.348$, *P* = .004 for normal BMI group).

4. Discussion

The most important result of this study is that the inhaled oxygen concentration did not have a significant effect on the incidence of postoperative atelectasis in normal-weight individuals,

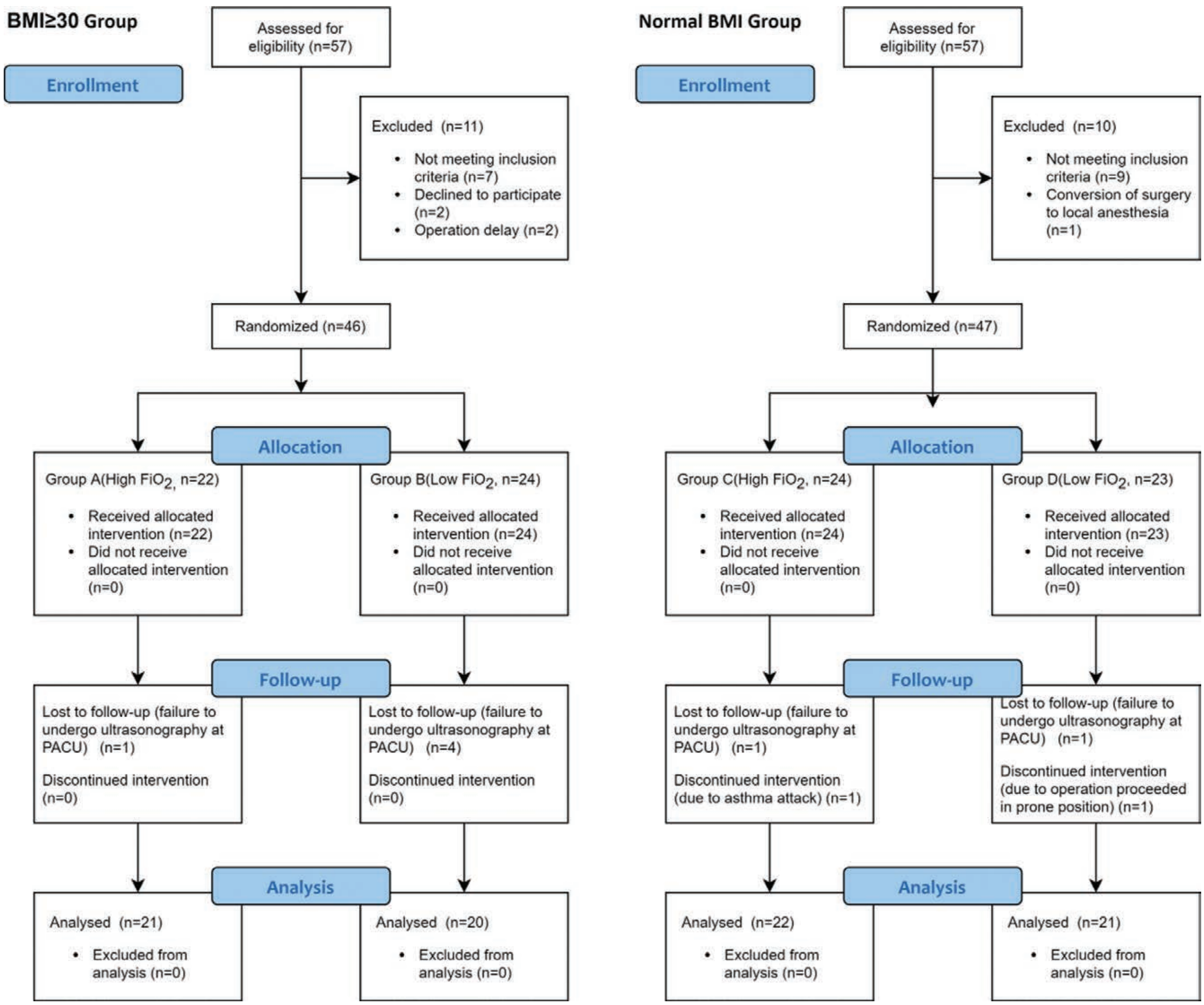

Figure 1. Flow diagram showing the selection of the study participants. BMI = body mass index, FiO_2 = fraction of inspired oxygen, PACU = postanesthesia care unit.

but there was a greater effect on the development of atelectasis with high inhaled oxygen concentration (100% oxygen) than with low inhaled oxygen concentration (40% oxygen) in obese patients. However, there were no significant effects on the arterial blood gas analysis (ABGA), SpO_2, desaturation events, or other respiratory complications.

According to our study results, if we interpret only the LUSS results performed after surgery in the BMI ≥ 30 group, similar to the results of a recent meta-analysis, there was no significant difference in the degree of atelectasis.[15–17] However, we believe that the difference in LUSS before and after surgery better reflects the rate of atelectasis after surgery and is important for clinically judging the risk and benefit of patients requiring high-concentration oxygen infusion.

In some studies using CT, the degree of atelectasis was not measured before surgery because of the risk of radiation exposure, or CT was taken in a narrow range.[25] However, it is important to measure the baseline atelectasis to compare the incidence of atelectasis in obese patients because obese patients may have a small area of atelectasis even during normal times as a result of dependent airway closure.[13] In many studies using lung ultrasonography, the degree of atelectasis was evaluated by using only LUSS. However, in our study, to correct the difference in the degree of atelectasis that the patient had before starting induction and to evaluate only the degree of atelectasis caused purely by anesthesia, the difference between the pre- and postoperative LUSS was set as the primary outcome.

According to a recent meta-analysis of 26 studies, a high FiO_2 significantly increased postoperative atelectasis and lowered PaO_2. However, when a subgroup analysis was performed on patients with a BMI >30, there was no significant difference between these 2 values.[17] Contrary to the results of a recent meta-analysis, if we interpret only the value of LUSS difference in the BMI ≥ 30 group, it can be said that a high concentration of inhaled oxygen increases the incidence of atelectasis in obese patients. Unlike previous meta-analyses, this study corrected for the degree of atelectasis that obese patients had before surgery, and it is thought that this is because only surgeries performed in a position that did not affect the development of atelectasis were included. The group receiving low concentrations of oxygen was controlled so as not to be exposed to high concentrations of oxygen, even for short periods such as induction and emergence. This is important because ventilation for only a few minutes with an inhaled oxygen concentration of 1.0 markedly increases atelectasis after induction compared with ventilation with lower oxygen concentration.[11,26] In addition, during normal respiration, the diaphragm contracts, pushing the abdominal contents down and forward, and contraction of the external intercostal muscles pulls the ribs upward and forward.[27]

Table 1

Characteristics of patients, surgery, and anesthetic in this study.

	BMI ≥ 30 group			normal BMI group		
	Group A (n = 21)	Group B (n = 20)	*P* value	Group C (n = 22)	Group D (n = 21)	*P* value
Age	48.76 ± 19.02	47.45 ± 14.09	.804	58.71 ± 13.07	53.86 ± 15.41	.273
Sex (M/F)	11 (52.38)/10 (47.62)	11 (55.00)/9 (45.00)	>.999	9 (42.86)/12 (57.14)	14 (63.64)/8 (36.36)	.227
BMI (kg/m²)	33.49 ± 5.64	32.87 ± 3.37	.477	24.69 ± 2.76	24.32 ± 2.76	.660
Comorbidity						
Current smoker (Y/N)	6 (28.57)/15 (71.43)	10 (50.00)/10 (50.00)	.208	6 (28.57)/15 (71.43)	6 (27.27)/16 (72.73)	>.999
Hypertension, n	10 (47.62)	4 (20.00)	.100	10 (47.62)	6 (27.27)	0.215
Diabetes mellitus, n	5 (23.81)	6 (30.00)	.734	5 (23.81)	6 (27.27)	>.999
Renal disease, n	5 (23.81)	0 (0.0)	.048*	4 (19.05)	2 (9.09)	.412
Angina, n	0 (0.0)	3 (15.00)	.107	4 (19.05)	0 (0.0)	.049*
Operative profiles						
Operation duration (min)	121.0 (85.00–145.00)	84.00 (42.00–129.25)	.151	118.00 (75.00–142.00)	84.00 (43.25–136.25)	.174
Anesthetic duration (min)	170 (125.00–205.00)	140.00 (87.50–170.00)	.090	180.00 (115.00–200.00)	137.50 (88.75–182.50)	.238
Total fluid (mL)	300 (200–500)	300 (200–500)	.875	450.00 (350–650)	400.00 (300–400)	.095
Urine output (mL)	170 (140–320)	290 (160–352.5)	.617	185 (160–352.5)	210 (140–250)	.629
Colloid use (Y/N)	0 (0.0)/ 21 (100.0)	2 (10.0)/18 (90.0)	.232	1 (4.76)/20 (95.24)	0 (0.0)/22 (100.0)	.488
Type of surgery, anesthesia						
Upper/lower extremity	4 (19.05)/17 (80.95)	3 (15.00)/17 (85.00)	>.999	0 (0)/21 (100)	1 (4.55)/21 (95.45)	>.999
PEEP application, n	11 (52.38)	10 (50.00)	>.999	11 (52.38)	11 (50.00)	>.999

Data are expressed as mean ± standard deviation or median (interquartile range), or number (%). BMI ≥ 30 group: group A using high FiO_2 and group B using low FiO_2. Normal BMI group: group C using high FiO_2 and group D using low FiO_2. Urine output was measured in patients with Foley catheter.

BMI = body mass index, FiO_2 = fraction of inspired oxygen, PEEP = positive end-expiratory pressure.

*$P < .05$.

Table 2

Preoperative and postoperative modified lung ultrasound scores (LUSS).

	BMI ≥ 30 group			normal BMI group		
	Group A (n = 21)	Group B (n = 20)	*P* value	Group C (n = 22)	Group D (n = 21)	*P* value
Before induction						
Total modified LUSS	11.05 ± 4.31	12.55 ± 4.41	.276	11.48 ± 3.66	10.59 ± 2.17	.344
Anterior regions	3 (2–4)	4 (4–5.25)	.065	4 (3–4)	4 (3–4)	.463
Lateral regions	4 (3–4)	4 (3–5)	.649	3.71 ± 1.74	3.55 ± 1.14	.707
Posterior regions	4 (2–5)	4 (3.75–6.25)	.326	4 (4–4)	4 (3–4)	.578
Postoperative (PACU)						
Total modified LUSS	17.43 ± 3.64	15.95 ± 4.77	.270	16.14 ± 3.69	13.50 ± 2.58	.009*
Anterior regions	5 (4–6)	5 (4–6)	.926	4 (4–6)	4 (4–4)	.228
Lateral regions	5.76 ± 1.58	5.00 ± 1.92	.172	5 (4–6)	4 (4–5)	.059
Posterior regions	7 (6–8)	6 (5–7)	.131	6 (5–8)	5 (4–6)	.032*
LUSS difference						
Total modified LUSS	6 (4–7)	3 (1–6)	.006*	3 (3–6)	2.50 (1–5)	.076
Anterior regions	2 (0–3)	1 (0–1)	.033*	1 (0–2)	0 (0–1)	.426
Lateral regions	2 (1–3)	1 (0–2)	.062	2 (1–2)	1 (0–1)	.051
Posterior regions	2 (2–4)	1 (0–2.25)	.014*	2 (1–3)	1 (0–2.75)	.133

Data are expressed as mean ± standard deviation or median (interquartile range). BMI ≥ 30 group: group A using high FiO_2 and group B using low FiO_2. Normal BMI group: group C using high FiO_2 and group D using low FiO_2. Anterior, lateral, and posterior regions of the thorax were divided by the anterior and posterior axillary lines.

BMI = body mass index, LUSS = lung ultrasound score, PACU = postanesthesia care unit.

*$P < .05$.

However, obese patients are affected in this normal mechanism because they have excess body fat that is distributed in the chest and takes up the abdomen and restricts the action of the respiratory muscles.[28] It reduces lung compliance, leading to mechanical impairment of the respiratory muscles and making it harder to compensate and overcome the loss of lung aeration after extubation using 100% oxygen than that seen with normal-weight individuals. This may explain why a significant difference was found only in the obese patient group.

Since the use of N_2O as a carrier gas increases the incidence of atelectasis, in a recent meta-analysis targeting only randomized controlled trials using air as a carrier gas, the occurrence of atelectasis increased significantly in the group with a high inhaled oxygen concentration, and there was no significant difference among patients with a BMI ≥ 30. Similarly, in our study, there was a difference in the LUSS values in the PACU, which indicates the degree of postoperative atelectasis in the group with normal BMI; however, there was no significant difference in the LUSS values before and after surgery.

Table 3

Perioperative PaO_2, PaO_2 to FiO_2 ratio from arterial blood gas analysis, SpO_2, desaturation event.

	BMI ≥ 30 group			normal BMI group		
	Group A (n = 21)	Group B (n = 20)	*P* value	Group C (n = 22)	Group D (n = 21)	*P* value
Baseline, preoperative						
SpO_2	97.67 ± 1.62	98.00 ± 1.41	.488	98.0 (98–100)	98.0 (97–99)	.663
Intraoperative						
PaO_2	185.50 (167.40–239.08)	120.65 (108.38–164.20)	.001*	240.32 ± 138.35	152.31 ± 53.77	.011*
PaO_2/FiO_2 (after induction)	371.00 (334.80–479.60)	301.63 (270.94–410.50)	.115	480.63 ± 276.70	380.77 ± 134.43	.002*
Desaturation event, n	0	0		0	0	
Postoperative (PACU)						
SpO_2	99.0 (97–100)	98.5 (98–100)	.517	98.0 (97–99)	99.0 (98–99)	.483
Desaturation event, n	3 (14.29)	2 (10)	>.999	1 (4.76)	0 (0.0)	.664
Postoperative day 1						
PaO_2	81.50 (70.50–95.00)	87.70 (79.38–98.03)	.197	82.50 (70.10–90.20)	88.30 (81.00–93.00)	.294
PaO_2/FiO_2	407.5 (326.50–475.00)	426.75 (391.50–481.63)	.309	412.50 (350.50–451.00)	441.50 (405.00–465.00)	.294
Desaturation event, n	3 (14.29)	2 (10.00)	>.999	4 (18.18)	2 (9.52)	.664

Data are expressed as mean ± standard deviation or median (interquartile range), or number (%). BMI ≥ 30 group: group A using high FiO_2 and group B using low FiO_2. Normal BMI group: group C using high FiO_2 and group D using low FiO_2.
BMI = body mass index, FiO_2 = fraction of inspired oxygen, PACU = postanesthesia care unit, PaO_2 = arterial partial pressure of oxygen, SpO_2 = oxygen saturation by pulse oximeter.
*$P < .05$.

Table 4

Postoperative outcomes.

	BMI ≥ 30 group			Normal BMI group		
	Group A (n = 21)	Group B (n = 20)	*P* value	Group C (n = 22)	Group D (n = 21)	*P* value
Postoperative d 1 outcome variables						
Fever within postoperative 24 h (>37.5°C), n	1 (4.76)	2 (10.00)	.606	1 (4.55)	1 (4.76)	>.999
Atelectasis on chest X-ray, n	2 (9.52)	1 (5.00)	>.999	1 (4.55)	1 (4.76)	>.999
Pneumonia on chest X-ray, n	1 (4.76)	0 (0.00)	>.999	0 (0)	0 (0)	-
Pulmonary congestion on chest X-ray, n	2 (9.52)	1 (5.00)	>.999	2 (9.09)	1 (4.76)	>.999
In-hospital pulmonary complication, n	6 (28.57)	4 (20.00)	.719	5 (22.73)	2 (9.52)	.412
Length of hospital d	7 (3–9)	4 (2–7)	.124	7 (5.25–10.75)	5 (2–7)	.040*

Data are expressed as median (interquartile range) or number (%). BMI ≥ 30 group: group A using high FiO_2 and group B using low FiO_2. Normal BMI group: group C using high FiO_2 and group D using low FiO_2.
BMI = body mass index, FiO_2 = fraction of inspired oxygen.
*$P < .05$.

Table 5

Multivariable analysis of factors associated with the LUSS difference value measured before induction and in PACU.

	BMI ≥ 30 group		Normal BMI group	
	β	*P* value	β	*P* value
PEEP	−2.443	.022*	−2.348	.004*
Age	0.004	.894	0.028	.303
Sex (reference: male)	−1.009	.339	1.119	.176
Anesthesia time (min)	0.006	.274	0.010	.088

Values are presented as coefficient; β and *P* value.
BMI = body mass index, LUSS = lung ultrasound score, PACU = postanesthesia care unit, PEEP = positive end-expiratory pressure.
*$P < .05$.

Contrary to the recent meta-analysis results, there may be several reasons for the lack of a significant difference in the rate of atelectasis when interpreted as the LUSS difference in the patient group with normal BMI. There were also compensatory adaptations for each patient.[9] Specifically, although unlikely in respiratory-compromised patients, healthy patients who are commonly included in many studies may compensate and overcome perioperative lung problems such as lung edema or atelectasis. In addition, there was a 20-minutes time gap between the end of the operation and ultrasonography, and the nurses in the recovery room managed the patients and often encouraged them to breathe deeply, which may have resulted in recovery of some of the atelectasis that occurred during the operation.[29,30] Unlike the studies of Akca et al[31] and Strandberg et al,[32] the primary outcome of our study was to evaluate the degree of atelectasis that occurred immediately after surgery when lung ultrasound was performed 20 min after arrival at the PACU. Lung ultrasound was intentionally performed in the PACU period, and not just before the end of surgery, to investigate the relationship between respiratory complications and the degree of atelectasis during the period most vulnerable to hypoxia immediately after surgery.

In many studies, the PaO_2 value was higher in the group inhaling low-concentration oxygen for all patients regardless of BMI,[6,17] but it was said that there was no significant difference in the group with a BMI ≥ 30.[17] In our study, there was no difference in PaO_2 values in patients with normal BMI as well as in patients with BMI ≥ 30. For patients who maintained oxygen even after surgery owing to desaturation, ABGA was performed with oxygen infused through the nasal cannula to prevent hypoxemia; therefore, they were not all in room air condition. To correct this, there was no significant difference between the groups, even in terms of the PaO_2/FiO_2 values. The difference from the previous results may have occurred because the time period during which ABGA was implemented varied.

There were no significant differences in fever, chest radiography abnormalities (atelectasis, pulmonary congestion), pneumonia, or pulmonary complications on the 1st day after surgery in all groups, which is consistent with the results of other meta-analysis.[17,33] Edmark et al reported that, at each of the inhaled oxygen concentrations of 60%, 80%, and 100%, the degree of atelectasis was different as the inhaled oxygen concentration increased until 14 minutes after initiation of preoxygenation and induction.[34] Nevertheless, according to Akca et al, when the inhaled oxygen concentration was 80% or 30%, there was no significant difference as a result of evaluating the incidence of atelectasis measured on the first postoperative day.[31] There is 1 randomized controlled double-blind study for postoperative atelectasis in obese patients. Similarly, in this study, the degree of atelectasis was determined using CT on the first postoperative day. In obese patients, when a high inhaled oxygen concentration (90%) was administered, more atelectasis was observed than when low inhaled oxygen (40%) was administered; however, no significant difference was found.[15] The results of comparing the difference in the incidence of atelectasis by chest radiography performed on the first postoperative day were consistent with the results of this study in that there was no significant difference between the obese and normal-weight patient groups. The influence of ventilator setting and inspired oxygen concentration is prone to overlap because patient factors or other factors influence patient prognosis much more.[35]

Although there was no difference according to the FiO_2 in hospital stay in previous studies,[17,33] our study showed that patients with normal BMI stayed significantly longer in the group with a high FiO_2. The reason for these results is not clear, but the hospital stay may be affected by other factors, such as hospitalization for knee surgery and staged bilateral knee surgery.

In the early days, the 6- or 8-region[36] method was used based on the simplified lung edema scoring system.[37] Recently, many studies have indicated that the 12-region method is now being more widely used[38] because the 12-region method may be more reliable because of less omission in the lung area without risk of radiation. Therefore, we used lung ultrasonography and the 12-region method in the present study. While early LUS used only longitudinal scans, we used longitudinal and transverse scans in combination at the same lung regions and obtained a higher score. This method was used to minimize possible limitations in the visualization of the pleura owing to the decreased intercostal space width.

In our study, although the setting of PEEP which is to be set autonomously was decided by the anesthesiologist in charge of surgery, PEEP was set to 5 cmH_2O, which is routinely used for anesthesia, for all patients with PEEP setting, and the number of patients with PEEP setting in each group was almost identical. In our subgroup analysis, the application of PEEP significantly reduced the occurrence of atelectasis in both groups. Alveolar recruitment can be obtained from PEEP and the lung-recruiting maneuver. Song et al reported that there was no significant difference in the occurrence of atelectasis at 60% and 30% inhaled oxygen concentrations when an ultrasound-guided recruitment maneuver was performed and PEEP of 5 cmH_2O was administered to pediatric patients on mechanical ventilation.[39] No agreement has been reached concerning the optimal PEEP for obese patients, but generally, high PEEP is associated with improved intraoperative oxygenation and reduced incidence of atelectasis.[40] Therefore, when using a high concentration of oxygen owing to the risk of hypoxia, it is better to administer PEEP if there are no contraindications. In particular, in obese patients whose postoperative atelectasis increases because of a high oxygen concentration, it is recommended to use a higher PEEP through methods such as the electrical impedance tomography-guided PEEP titration procedure[41] or the lung ultrasound-guided recruitment maneuver.

Our study has several limitations. First, ultrasound is an operator-dependent imaging modality,[42] and the observed findings may vary based on the operator's experience. However, the anesthesiologists who performed ultrasound of the lungs in our study were experienced in lung ultrasound examination, and therefore, operator-related variations were minimal. Second, blinding was not performed because the person who performed the lung ultrasound could determine whether the patient was obese or had a normal BMI by inspecting the patient's somatotype. However, anesthesiologists who performed the lung ultrasound did not know the inhaled oxygen concentration received by the patient. Third, the 40% inhaled oxygen concentration used in our study may not have been sufficiently low. Rothen et al reported that when 30% inhaled oxygen concentration was used during induction and anesthesia, atelectasis hardly occurred until approximately 40 minutes after induction, even without PEEP application. However, the use of an oxygen concentration of 30% for induction and extubation is not recommended in obese patients because the time at which desaturation occurs during apnea is decreased.[11] Fourth, PEEP, an important factor in the development of atelectasis, was not controlled; setting it was left to the independent judgment of the anesthesiologist in charge of surgery to cope with intraoperative desaturation that may occur owing to low inhaled oxygen concentration in the obese group. As mentioned above, since the patients who were administered PEEP were similar in each group, this was not expected to significantly affect the interpretation of the results. Fifth, the patients enrolled in our study included only those without serious cardiopulmonary disease; therefore, the results may not be identical in patients with multiple comorbidities.

So far, it is controversial whether high-concentration inhaled oxygen is beneficial to patients.[43] In order to prevent desaturation in various situations such as difficult intubation, a high concentration of inhaled oxygen helps to create a sufficient oxygen reserve. According to the recent recommendation of World Health Organization, to reduce the risk of surgical site infection, it is recommended to use high concentration (FiO_2 0.8) inhaled oxygen not only during surgery but also immediate postoperative period for 2 to 6 hours.[44] However, this guideline has limitations in that it is based on meta-analysis that includes heterogenous studies, and there is also a study that it is effective in preventing surgical site infection only for patients in a subgroup undergoing colorectal surgery.[45] There are also studies showing the opposite result,[46,47] and there are studies showing that hyperoxia increased mortality in critically ill patients.[48]

In this respect, we think that our study has the strength in that it is a prospective randomized controlled trial with well controlled various factors that can affect atelectasis except inhaled oxygen concentration. So far, we think that the inhaled oxygen fraction should be determined on a case-by-case basis by considering the risks and benefits according to the patient and the type of surgery. It is hoped that the results of this study will be helpful in determining what oxygen concentration should be used for ventilation during surgery, at least in obese patients who do not have serious cardiopulmonary problems. In the future, a large prospective randomized controlled study will be needed for each patient group with various comorbidities or undergoing different types of surgery.

5. Conclusion

In conclusion, a high inhaled oxygen concentration (100% oxygen) in obese patients can have a more significant effect on the development of atelectasis than a low inhaled oxygen concentration (40% oxygen); however, inhaled oxygen concentration in normal-weight individuals did not have a significant effect on the incidence of postoperative atelectasis.

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