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Evaluation of the effects of preoxygenation with different oxygen concentrations during spontaneous breathing before anesthesia induction using lung ultrasonography

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ABSTRACT

Aims: To compare lung aeration loss after preoxygenation with 80% or 100% fraction of inspired oxygen (FiO_2) during spontaneous breathing before induction of general anesthesia using the modified lung ultrasound score (MLUS).

Methods: Fifty-four ASA I–II adults aged 18–65 years without known pulmonary disease were randomized before elective surgery to three-minute spontaneous-breathing preoxygenation with 80% FiO_2 (group E) or 100% FiO_2 (group H). After four post-randomization exclusions, 50 patients were included in the analysis (25 per group). Lung ultrasonography was performed in 12 thoracic regions before and after preoxygenation by an investigator blinded to group allocation. Total MLUS scores, peripheral oxygen saturation, end-tidal oxygen (EtO_2), and ultrasound assessment duration were recorded.

Results: Demographic and clinical characteristics were similar between groups. Post-preoxygenation EtO_2 was higher in group H than in group E ($p<0.001$). Total MLUS scores increased from baseline in both groups ($p<0.001$ for both). The proportion of patients with a post-preoxygenation total MLUS score >0 was 76% in group E and 92% in group H ($p=0.247$). However, the post-preoxygenation total MLUS score was higher in group H than in group E [5.0 (0.0-11.0) vs 3.0 (0.0-6.0); $p=0.002$]. Exploratory regional analyses showed a between-group difference in post-preoxygenation MLUS scores in the combined lateral region (unadjusted $p=0.001$).

Conclusion: Preoxygenation during spontaneous breathing increased total MLUS scores with both 80% and 100% FiO_2. Although 100% FiO_2 achieved higher EtO_2, it was associated with higher total MLUS scores than 80% FiO_2; the clinical implications of this sonographic difference remain uncertain.

Keywords: Pulmonary atelectasis, ultrasonography, anesthesia, oxygen, oxygen inhalation therapy

INTRODUCTION

Atelectasis is defined as impaired gas exchange in an affected lung region resulting from complete or partial collapse of the lung.[1] It may occur in up to 90% of patients undergoing general anesthesia and is among the most common perioperative pulmonary problems.[2] Atelectasis may be associated with impaired oxygenation, decreased lung compliance, ventilation-perfusion mismatch, and hypoxemia. During general anesthesia, decreased muscle tone and cranial displacement of the diaphragm reduce functional residual capacity. Airway closure, particularly in dependent lung regions, and absorption of distal alveolar gas into the blood contribute to the development of absorption atelectasis. A high fraction of inspired oxygen (FiO_2) may accentuate this process by accelerating alveolar nitrogen washout.[3]

Preoxygenation is performed before induction of general anesthesia to increase body oxygen stores, reduce the risk of hypoxemia, and prolong the safe apnea time. The American Society of Anesthesiologists (ASA) difficult airway management guidelines recommend preoxygenation before airway interventions.[4] However, high oxygen concentrations may increase absorption atelectasis; therefore, an appropriate balance should be maintained between adequate oxygen reserve and preservation of lung aeration.[5]

Lung ultrasonography is a bedside, repeatable imaging method that does not involve ionizing radiation. The modified lung ultrasound score (MLUS) allows perioperative aeration loss to be monitored by including small subpleural

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consolidations in addition to B-lines and consolidations.[6] This study aimed to compare sonographic changes consistent with atelectasis using MLUS in patients preoxygenated with 80% or 100% FiO_2 during spontaneous breathing before induction of general anesthesia.

METHODS

Ethics

This study was conducted with the approval of the Clinical Researches Ethics Committee No. 1 of Ankara Etlik City Hospital (Date: 22.03.2023, Decision No: AESH-EK1-2023-001). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. Written informed consent was obtained from all individual participants prior to their inclusion in the study.

Study Design

This study was designed as a randomized, prospective, observer-blinded, parallel-group clinical study. The study was registered at ClinicalTrials.gov under the registration number NCT05850988. The study was conducted between April and May 2023 in accordance with the Good Clinical Practice principles. After patients were informed about the aim, method, potential benefits, and risks of the study, written informed consent was obtained from all participants.

Participants and Randomization

Between April and May 2023, 70 patients scheduled for elective surgery under general anesthesia in the operating room of Ankara Etlik City Hospital were assessed for eligibility. Sixteen patients who met the exclusion criteria were not included. Fifty-four patients who met the inclusion criteria were randomized in a 1:1 ratio to group E (preoxygenation with 80% FiO_2) or group H (preoxygenation with 100% FiO_2) using a randomization table generated with MedCalc 20.218. In group H, 2 patients were excluded because of face-mask intolerance during preoxygenation. In group E, 1 patient was excluded because baseline ultrasonography showed pleural effusion and parenchymal changes suggestive of lung contusion, and 1 patient was excluded because splenomegaly causing marked left hemidiaphragm elevation was detected. Thus, four patients were excluded after randomization for the reasons described above. The analysis population comprised the remaining 50 patients (25 in each group), who completed the assigned preoxygenation procedure and both baseline and post-preoxygenation lung ultrasonography assessments (Figure 1).

Patients aged 18-65 years, with ASA physical status I-II, and scheduled for elective surgery under general anesthesia were included. Patients with known obstructive or restrictive pulmonary disease; a history of pulmonary infection, surgery, or multiple trauma within the previous three months; a BMI of 30 or higher; pregnancy; diaphragmatic hernia; a diagnosis of gastroesophageal reflux disease; or current smoking were excluded because these factors predispose patients to atelectasis and other pulmonary complications.

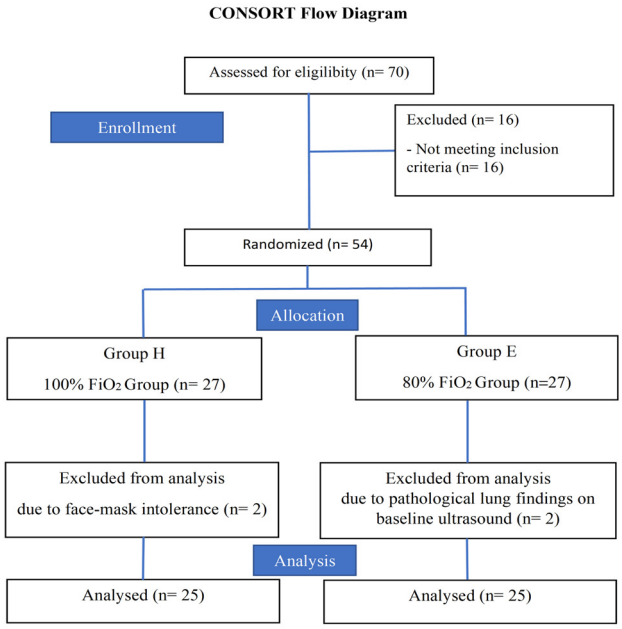

Figure 1. CONSORT flow diagram showing participant assessment, randomization, allocation, exclusions after allocation, and inclusion in the final analysis
CONSORT: Consolidated Standards of Reporting Trials; FiO_2: Fraction of inspired oxygen

Preoxygenation and Lung Ultrasonography Procedures

In the preoperative assessment room, patients underwent lung ultrasonography for baseline MLUS assessment before preoxygenation. The modified lung ultrasound scoring system described by Monastesse et al.[6] was used for MLUS assessment. The thorax was divided into 12 regions using the midsternal, anterior axillary, and posterior axillary lines as reference lines. Regions 1, 2, 3, and 4 were grouped as anterior; regions 5, 6, 7, and 8 as lateral; and regions 9, 10, 11, and 12 as posterior (Figure 2). Each region was scored from 0 to 3 according to the MLUS system, and the sum of scores from the 12 regions was recorded as the total MLUS score (Figure 3). The scoring criteria for each MLUS grade are presented in Supplementary Table.

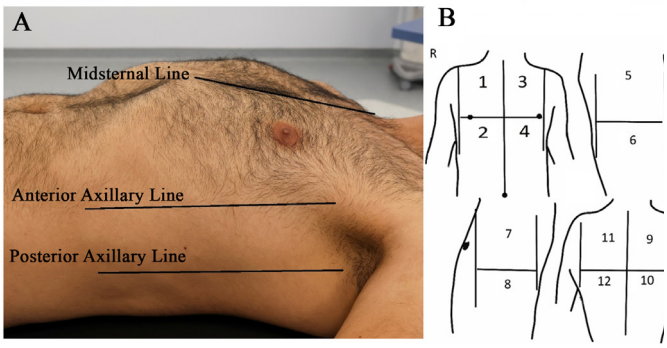

Figure 2. Schematic representation of the 12 thoracic regions assessed by lung ultrasonography. (A) Anatomical reference lines used to divide the thorax into anterior, lateral, and posterior regions: the midsternal line, anterior axillary line, and posterior axillary line. (B) Numbering of the 12 thoracic regions evaluated in the study. Each hemithorax was divided into anterior, lateral, and posterior regions, and each region was further subdivided into upper and lower zones

Lung ultrasonography was performed in B-mode using a Logiq P9 ultrasound system (GE Healthcare, USA) and a 2-9 MHz convex probe. MLUS values, ASA physical status,

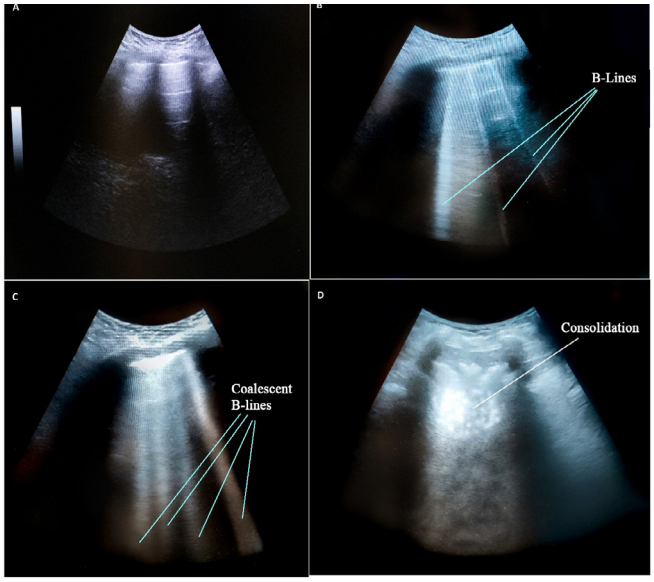

Figure 3. Representative lung ultrasonography images according to the modified lung ultrasound score. (A) Score 0: normal lung pattern with 0-2 B-lines. (B) Score 1: three or more B-lines or one or more subpleural consolidations separated by a normal pleural line. (C) Score 2: multiple coalescent B-lines or multiple small subpleural consolidations associated with a thickened or irregular pleural line. (D) Score 3: consolidation or subpleural consolidation larger than 1×2 cm

Supplementary Table. Modified lung ultrasound scoring system

MLUS score	Ultrasonographic findings
0	Normal lung pattern with 0-2 B-lines
1	Three or more B-lines or one or more subpleural consolidations separated by a normal pleural line
2	Multiple coalescent B-lines or multiple small subpleural consolidations associated with a thickened or irregular pleural line
3	Consolidation or subpleural consolidation larger than 1×2 cm

MLUS: Modified lung ultrasound score

comorbidities, age, gender, height, and body weight were recorded on the case report form. No patient received premedication.

After baseline MLUS assessment, patients were transferred to the operating room. Standard monitoring, including SpO_2, noninvasive blood pressure, and electrocardiography, was applied to all patients. On the Dräger Primus® anesthesia machine with integrated anesthetic gas monitoring, the FiO_2 value was set according to the patient's randomized group. Fresh gas flow was set at 5 L/min, and the APL valve was set to the spontaneous breathing position. The FiO_2 was set according to the randomized group, and the FiO_2 display on the anesthesia machine was covered with opaque paper before preoxygenation. The investigator performing lung ultrasonography remained blinded to group allocation until completion of the second ultrasound assessment.

FiO_2 was set to 80% in group E and 100% in group H. Patients were preoxygenated for three minutes in the supine position during spontaneous breathing using a leak-free face mask selected according to facial structure and connected to the Y-piece of the circle breathing system of the anesthesia machine.[7] Face-mask fit was assessed based on appropriate $EtCO_2$ values and capnogram pattern, with no visible leak around the mask.

At the end of the three-minute preoxygenation period, a second lung ultrasonography assessment was performed while patients were still breathing spontaneously, and MLUS values were recorded. During assessment of the posterior quadrants, patients were asked to turn slightly from the supine position. After completion of ultrasonography, EtO_2 and SpO_2 values at the end of preoxygenation and the time required to assess all 12 thoracic regions were recorded.

After study measurements were completed, general anesthesia induction was performed according to the preference of the anesthesiologist responsible for the case. Patients were intubated with an endotracheal tube to secure the airway during surgery. Intraoperatively, patients were ventilated with a tidal volume of 6-8 ml/kg according to ideal body weight, a respiratory rate of 10-14 breaths/min, and 5-8 cm H_2O positive end-expiratory pressure. In patients with findings consistent with atelectasis on MLUS assessment before or after preoxygenation, an alveolar recruitment maneuver was performed after completion of study measurements using sustained insufflation at 30 cm H_2O for 30 seconds.

Outcome Measures

The primary outcome was the comparison of post-preoxygenation total MLUS score between group E and group H. Secondary outcome measures were the within-group change in total MLUS score from baseline to after preoxygenation, the proportion of patients with a total MLUS score >0, regional MLUS scores in the 12 thoracic regions, MLUS scores for the anterior, lateral, and posterior regions, SpO_2 values before and after preoxygenation, EtO_2 at the end of preoxygenation, and the time required for ultrasonographic assessment of the 12 thoracic regions.

Statistical Analysis

Sample size was calculated using OpenEpi based on data reported in previous literature.[8] With a two-sided alpha level of 0.05, 80% power, and a 1:1 allocation ratio, the minimum required sample size was 44 patients (22 per group) using the Fleiss method with continuity correction. To compensate for possible exclusions, 50 patients were planned for inclusion in the study.

The analyses were restricted to the 50 evaluable participants (25 in each group) who completed the assigned preoxygenation procedure and both baseline and post-preoxygenation lung ultrasonography assessments. Four of the 54 randomized patients were excluded from the analyses for the reasons described in the Participants and Randomization section. Therefore, an intention-to-treat analysis was not performed. Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) version 21.0. Categorical variables are presented as number (n) and percentage (%). The normality of continuous variables was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests, and homogeneity of variance was assessed using Levene's test.

Continuous variables that were normally distributed and met parametric assumptions are presented as mean±standard

deviation (mean±SD), and between-group comparisons were performed using Student's t-test. Non-normally distributed continuous variables and ordinal data are presented as median (minimum-maximum); between-group comparisons were performed using the Mann-Whitney U (MWU) test, and within-group repeated measurements were compared using the Wilcoxon signed-rank test.

Categorical variables were compared between groups using the Pearson Chi-square test, and Fisher's exact test was used when the expected cell count was insufficient. Fisher's exact test was also used for comparisons in which total MLUS score was classified as =0 or >0. Regional MLUS comparisons were exploratory; their p-values were not adjusted for multiple comparisons and were interpreted descriptively. For nonregional analyses, a p-value <0.05 was considered statistically significant.

RESULTS

Between April and May 2023, 70 patients scheduled for elective surgery under general anesthesia were assessed for eligibility, and 54 were randomized (27 to each group). Following four exclusions after randomization, 50 patients were included in the final analysis (25 in each group; Figure 1). Of these patients, 27 (54%) were male and 23 (46%) were female. Patients were analyzed in two groups: group E (preoxygenation with 80% FiO_2, n=25) and group H (preoxygenation with 100% FiO_2, n=25).

There were no significant differences between group E and group H in age (34.2±12.2 years vs 34.6±12.1 years; p=0.917) or BMI (24.9±3.1 kg/m² vs 25.0±3.4 kg/m²; p=0.904). The groups were also similar in terms of gender, presence of comorbidity, ASA class, and BMI category (p>0.05 for all comparisons) (Table 1).

Table 1. Comparison of demographic and clinical characteristics between groups

	Group E (n=25)	Group H (n=25)	p
Age, years	34.2±12.2	34.6±12.1	0.917
Body weight, kg	70.0±13.0	71.7±11.4	0.614
Height, m	1.7±0.1	1.7±0.1	0.437
BMI, kg/m²	24.9±3.1	25.0±3.4	0.904
Gender (male/female), n (%)	14 (56.0)/11 (44.0)	13 (52.0)/12 (48.0)	0.777
Comorbidity, n (%)	5 (20.0)	6 (24.0)	0.733
ASA (I/II), n (%)	20 (80.0)/5 (20.0)	19 (76.0)/6 (24.0)	0.733
Overweight, n (%)	12 (48.0)	13 (52.0)	0.777

Data are presented as mean±standard deviation or n (%). Student's t-test was used for between-group comparisons of continuous variables, and Pearson Chi-square test was used for comparisons of categorical variables. p<0.05 was considered statistically significant. Normal BMI was defined as 18.5–24.9 kg/m² and overweight as 25.0–29.9 kg/m². BMI: Body-mass index, ASA: American Society of Anesthesiologists, kg: kilograms; m: meters, kg/m²: Kilograms per square meter

Post-preoxygenation EtO_2 was 67.0 (51.0-81.0) in group E and 77.0 (64.0-95.0) in group H and was significantly higher in group H (p<0.001). The lung ultrasonography assessment duration was 316.0 (240.0-380.0) seconds in group E and 311.0 (267.0-381.0) seconds in group H, with no significant difference between groups (p=0.994) (Table 2).

Table 2. Comparison of EtO_2 and assessment duration between groups

	Group E (n=25)	Group H (n=25)	p
EtO_2, %	67.0 (51.0–81.0)	77.0 (64.0–95.0)	<0.001
Duration, s	316.0 (240.0–380.0)	311.0 (267.0–381.0)	0.994

Data are presented as median (minimum–maximum). The Mann–Whitney U test was used for between-group comparison. p<0.05 was considered statistically significant. EtO_2: End-tidal oxygen, FiO_2: Fraction of inspired oxygen, s: Seconds

In both groups, post-preoxygenation SpO_2 values increased significantly compared with baseline values (p<0.001 for both groups). The initial SpO_2 value was 99.0 (96.0-100.0) in group E and 98.0 (96.0-100.0) in group H, with no significant difference between groups (p=0.937). Post-preoxygenation SpO_2 was 100.0 (99.0-100.0) in both groups, and no significant difference was observed between groups (p=0.556) (Table 3).

Table 3. Between-group and within-group comparison of SpO_2 values

	Group E (n=25)	Group H (n=25)	p
Initial SpO_2, %	99.0 (96.0–100.0)	98.0 (96.0–100.0)	0.937
Final SpO_2, %	100.0 (99.0–100.0)	100.0 (99.0–100.0)	0.556
Within-group p	<0.001	<0.001	

Data are presented as median (minimum–maximum). The Mann–Whitney U test was used for between-group comparisons, and the Wilcoxon signed-rank test was used for within-group comparison of initial and final measurements. p<0.05 was considered statistically significant. SpO_2: Peripheral oxygen saturation, FiO_2: Fraction of inspired oxygen

At baseline assessment, the total MLUS score was 0 in 22 patients (88%) in group E and in 22 patients (88%) in group H, and the distribution of patients with a total MLUS score =0 and >0 was similar between groups (p=0.999). After preoxygenation, the number of patients with a total MLUS score >0 was 19 (76%) in group E and 23 (92%) in group H. Although this proportion was higher in group H, the difference between groups was not statistically significant (p=0.247) (Table 4).

Table 4. Between-group comparison of MLUS scores classified as 0 and greater than 0

	Group E (n=25)	Group H (n=25)	p
Baseline total MLUS score =0, n (%)	22 (88.0)	22 (88.0)	0.999
Baseline total MLUS score >0, n (%)	3 (12.0)	3 (12.0)	
Post-preoxygenation total MLUS score =0, n (%)	6 (24.0)	2 (8.0)	0.247
Post-preoxygenation total MLUS score >0, n (%)	19 (76.0)	23 (92.0)	

Data are presented as n (%). At each assessment time point, the total MLUS score was classified into two categories: MLUS score =0 and MLUS score >0. Between-group comparisons were performed using Fisher's exact test based on 2×2 contingency tables constructed for each assessment time point. Therefore, p-values do not refer to a single row or a single category, but to the overall distribution of the two categories at the corresponding assessment time point. The baseline p-value compares the distribution of patients with a total MLUS score =0 and >0 between group E and group H; the post-preoxygenation p-value compares the distribution of patients with a total MLUS score =0 and >0 between group E and group H. p<0.05 was considered statistically significant. MLUS: Modified lung ultrasound score

Baseline total MLUS scores were 0.0 (0.0-2.0) in group E and 0.0 (0.0-3.0) in group H, with no significant difference between groups (p=0.986). Post-preoxygenation total MLUS scores increased significantly from baseline in both groups (p<0.001 for both groups). The post-preoxygenation total MLUS score was 3.0 (0.0-6.0) in group E and 5.0 (0.0-11.0) in group H and was significantly higher in Group H (p=0.002) (Table 5).

Although the proportion of patients with a post-preoxygenation total MLUS score >0 was higher in group H,

Table 5. Within-group and between-group comparison of baseline and post-preoxygenation total MLUS scores

	Group E (n=25)	Group H (n=25)	Between-group p
Baseline total MLUS score	0.0 (0.0–2.0)	0.0 (0.0–3.0)	0.986
Post-preoxygenation total MLUS score	3.0 (0.0–6.0)	5.0 (0.0–11.0)	0.002
Within-group p	<0.001	<0.001	

MLUS scores are presented as median (minimum–maximum). Between-group p-values refer to the comparison of total MLUS scores between group E and group H at the corresponding assessment time point and were calculated using the Mann–Whitney U test. Within-group p-values refer to the paired comparison of baseline and post-preoxygenation total MLUS scores within the same group and were calculated using the Wilcoxon signed-rank test. A higher MLUS score indicates more pronounced loss of lung aeration. p<0.05 was considered statistically significant. MLUS: Modified lung ultrasound score

this difference was not statistically significant. However, the significantly higher total MLUS score in group H indicates that preoxygenation with 100% FiO_2 was associated with higher total MLUS scores.

When baseline MLUS scores were compared across the 12 defined thoracic regions, no statistically significant differences were found between group E and group H in any region (p>0.05 for all comparisons). In the exploratory post-preoxygenation analyses, nominal between-group differences in MLUS score distributions were observed in regions 5, 6, 7, 8, 9, 10, and 12 (all p<0.05; Table 6). Although these findings suggest regional differences in sonographic lung aeration loss between the groups, no adjustment for multiple comparisons was performed; therefore, the regional results should be interpreted cautiously.

Baseline MLUS scores in the anterior, lateral, and posterior regions were similar between group E and group H (p>0.05 for all comparisons). Following preoxygenation, the median MLUS score in the lateral region was higher in group H than in group E (2.00 vs. 0.00; nominal p=0.001), whereas the between-group comparisons in the anterior and posterior regions yielded p-values of 0.394 and 0.059, respectively (Table 7). Within-group comparisons yielded nominal p-values below 0.05 for the lateral and posterior regions in group E and for all three regions in group H. As no adjustment for multiple comparisons was performed, these regional findings are exploratory and should be interpreted cautiously.

DISCUSSION

The main finding of this study was that three minutes of preoxygenation during spontaneous breathing increased lung aeration loss in both the 80% and 100% FiO_2 groups, and that the post-preoxygenation total MLUS score was higher in the 100% FiO_2 group. In contrast, the difference between groups in the proportion of patients with an MLUS score greater than zero was not statistically significant. Accordingly, the between-group difference in total MLUS score should be interpreted as a difference in sonographic lung aeration loss rather than evidence of clinically significant atelectasis or improved postoperative pulmonary outcomes, which were not assessed in this study.

Table 6. Between-group comparison of baseline and post-preoxygenation MLUS scores according to the assessed region

	Baseline MLUS			Post-preoxygenation MLUS		
	Group E (n=25)	Group H (n=25)	p	Group E (n=25)	Group H (n=25)	p
	Median (min–max)	Median (min–max)		Median (min–max)	Median (min–max)	
1	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.999	0.00 (0.00–0.00)	0.00 (0.00–1.00)	0.153
2	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.999	0.00 (0.00–1.00)	0.00 (0.00–1.00)	0.999
3	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.999	0.00 (0.00–0.00)	0.00 (0.00–1.00)	0.317
4	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.999	0.00 (0.00–1.00)	0.00 (0.00–1.00)	0.641
5	0.00 (0.00–1.00)	0.00 (0.00–0.00)	0.317	0.00 (0.00–2.00)	0.00 (0.00–1.00)	0.019*
6	0.00 (0.00–0.00)	0.00 (0.00–1.00)	0.153	0.00 (0.00–1.00)	1.00 (0.00–2.00)	0.004*
7	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.999	0.00 (0.00–1.00)	0.00 (0.00–1.00)	0.018*
8	0.00 (0.00–0.00)	0.00 (0.00–1.00)	0.317	0.00 (0.00–1.00)	1.00 (0.00–1.00)	0.043*
9	0.00 (0.00–1.00)	0.00 (0.00–0.00)	0.317	0.00 (0.00–2.00)	1.00 (0.00–2.00)	0.016*
10	0.00 (0.00–1.00)	0.00 (0.00–1.00)	0.999	1.00 (0.00–2.00)	1.00 (0.00–2.00)	0.049*
11	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.999	0.00 (0.00–1.00)	0.00 (0.00–1.00)	0.139
12	0.00 (0.00–1.00)	0.00 (0.00–1.00)	0.999	1.00 (0.00–1.00)	1.00 (0.00–2.00)	0.013*

Data are presented as median (minimum–maximum). Between-group comparisons were performed using the Mann–Whitney U test for each assessed region. p-values indicate the comparison of score distributions between group E and group H in the corresponding region. Regional comparisons were evaluated descriptively. * indicates a nominal p-value <0.05 (uncorrected for multiple comparisons). No adjustment for multiple comparisons was performed. Therefore, regional analyses should be interpreted as exploratory, and the reported p-values should be interpreted cautiously. FiO_2: fraction of inspired oxygen; MLUS: Modified lung ultrasound score, Min: Minimum, Max: Maximum

Table 7. Within-group and between-group comparison of baseline and post-preoxygenation MLUS scores according to predefined regions

	Group E (n=25)			Group H (n=25)			Between p	
	Baseline	Post	Within p	Baseline	Post	Within p	Baseline	Post
Anterior	0.00 (0.00–0.00)	0.00 (0.00–1.00)	0.083	0.00 (0.00–0.00)	0.00 (0.00–2.00)	0.038*	0.999	0.394
Lateral	0.00 (0.00–1.00)	0.00 (0.00–3.00)	0.007*	0.00 (0.00–2.00)	2.00 (0.00–5.00)	<0.001*	0.540	0.001*
Posterior	0.00 (0.00–2.00)	2.00 (0.00–4.00)	<0.001*	0.00 (0.00–1.00)	3.00 (0.00–5.00)	<0.001*	0.967	0.059

MLUS scores are presented as median (minimum–maximum). Within p-values refer to within-group comparisons between baseline and post-preoxygenation MLUS scores and were calculated using the Wilcoxon signed-rank test. Between p-values refer to between-group comparisons of score distributions between group E and group H at the corresponding assessment time point and were calculated using the Mann–Whitney U test. * indicates a nominal p-value <0.05 (uncorrected for multiple comparisons). No adjustment for multiple comparisons was performed. Therefore, regional analyses should be interpreted as exploratory, and the reported p-values should be interpreted cautiously. MLUS: Modified lung ultrasound score

Lung ultrasonography is a rapid, radiation-free method that allows bedside assessment of perioperative atelectasis. In a pediatric study comparing lung ultrasonography with magnetic resonance imaging, lung ultrasonography showed 88% sensitivity and 89% specificity for anesthesia-induced atelectasis.[9] Similarly, high diagnostic performance has been reported in an adult study comparing lung ultrasonography with computed tomography.[10] The MLUS system used in the present study includes small subpleural consolidations and is therefore suitable for monitoring limited aeration changes that occur after a short intervention such as preoxygenation.[6] However, the relationship between score changes and clinical outcomes was not evaluated in this study.

High oxygen concentrations have previously been shown to increase perioperative atelectasis. Edmark et al.[11] compared preoxygenation with 60%, 80%, and 100% oxygen and found more atelectasis in the 100% oxygen group. In a randomized study of infants, preservation of spontaneous breathing was associated with less atelectasis than manual positive-pressure ventilation.[8] Clinical studies examining different FiO_2 levels have reported that a higher FiO_2 may be associated with atelectasis or sonographic aeration loss, while the clinical effects of perioperative high FiO_2 have also been evaluated in systematic reviews.[12-14] Our findings are consistent with these studies in that MLUS scores were higher after preoxygenation with 100% FiO_2.

A distinctive feature of our study is that all ultrasonography measurements were completed before premedication, anesthesia induction, neuromuscular blockade, intubation, and mechanical ventilation. Therefore, the observed changes are related to the preoxygenation period independently of the effects of surgery, positioning, controlled ventilation, or anesthetic drugs. Nevertheless, the increase in MLUS in both groups suggests that preservation of spontaneous breathing does not completely prevent early aeration loss associated with high oxygen concentrations. The lower MLUS values observed in our study compared with those reported during general anesthesia, surgery, or the postoperative period may also be explained by this early assessment time point.[6,15]

When the regional distribution of sonographic lung aeration loss was evaluated, exploratory within-group analyses yielded nominal p-values below 0.05 for the lateral and posterior regions in the 80% FiO_2 group and for the anterior, lateral, and posterior regions in the 100% FiO_2 group. In the post-preoxygenation between-group comparisons, a nominal difference was observed in the lateral region ($p=0.001$), but not in the anterior or posterior regions ($p=0.394$ and $p=0.059$, respectively). Previous computed tomography and ultrasonography studies have shown that anesthesia-related atelectasis is concentrated particularly in dependent posterior lung regions.[8,11,15,16] However, the within-group findings do not establish a broader anatomical distribution of lung aeration loss in the 100% FiO_2 group. As no adjustment for multiple comparisons was performed, these regional findings should be interpreted cautiously.

At the end of the three-minute preoxygenation period, EtO_2 was higher in the 100% FiO_2 group; however, median EtO_2 values in both groups remained below the 90% target commonly used as an indicator of adequate denitrogenation.[17] Previous studies have also reported that some patients do not reach target EtO_2 levels with standard preoxygenation methods.[18] Although face-mask fit was confirmed by capnography and visual assessment of mask leak in our study, the fixed three-minute duration, individual respiratory characteristics, and anatomical differences may have affected achievement of the target value. The median EtO_2 values below 90% suggest that complete denitrogenation may not have been achieved in either group under the study protocol. Although 80% FiO_2 was associated with lower post-preoxygenation MLUS scores, our data do not establish whether this approach provides an oxygen reserve or safe apnea time comparable to that achieved with 100% FiO_2. This uncertainty is particularly relevant to patients with anticipated difficult airways, in whom the potential benefit of lower sonographic aeration loss must be weighed against the need to establish an adequate oxygen reserve before anesthesia induction.

Limitations

This study has several limitations. The sample size was limited, and patients with obesity, smoking, known lung disease, or other pulmonary risk factors were excluded; therefore, the findings cannot be generalized to high-risk groups. Ultrasonography was performed only before and immediately after preoxygenation, and changes during general anesthesia and the postoperative period, as well as pulmonary complications, were not evaluated. Safe apnea time and peri-induction hypoxemia were not assessed; therefore, the lower MLUS scores observed with 80% FiO_2 cannot establish an oxygen reserve or clinical safety comparable to that achieved with 100% FiO_2. MLUS assessment was performed using a single imaging method, and a reference method such as computed tomography was not used. In addition, lung ultrasonography is operator-dependent, and interobserver agreement was not assessed in this study. Regional MLUS analyses were exploratory, and no adjustment for multiple comparisons was performed; therefore, these findings should be interpreted cautiously. The results should be confirmed in studies with larger sample sizes, different risk groups, and postoperative clinical outcomes.

CONCLUSION

Three minutes of preoxygenation during spontaneous breathing was associated with an increase in total MLUS score with both 80% and 100% FiO_2. Although the 100% FiO_2 group had higher EtO_2 and higher post-preoxygenation total MLUS scores than the 80% FiO_2 group, the clinical implications of these sonographic differences remain uncertain. Larger studies evaluating the effects of lower FiO_2 during preoxygenation on oxygen reserve, sonographic aeration loss, and postoperative clinical outcomes in low-risk elective surgical patients are needed.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was conducted with the approval of the Clinical Researches Ethics Committee No. 1 of Ankara Etlik City Hospital (Date: 22.03.2023, Decision No: AESH-EK1-2023-001).

Informed Consent

Written informed consent was obtained from all individual participants prior to their inclusion in the study. Participants were fully informed about the study's aims, procedures, potential risks and benefits, and their rights-including the right to withdraw at any time without consequence. All participants voluntarily signed a written informed consent form.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

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Author Contributions

Concept: AM; Design: DÖ; Control: DÖ; Resources: AM; Materials: AM; Data Collection and/or Processing: AM; Analysis and/or Interpretation: DÖ; Literature Review: AM; Article Writing: AM; Critical Review: All Authors.

Editor Note

Derya Özkan is a member of the Editorial Board of this journal. She was not involved in the editor assignment, reviewer selection, peer review process, or editorial decision for this manuscript. The peer review process was managed independently by another editor.

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