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Lung ultrasound imaging and clinical consequences of intraoperative high inspired oxygen fraction in healthy mechanically ventilated children

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ABSTRACT

Study objective: High inspired oxygen concentrations (FiO2) are claimed to cause resorption atelectasis increasing the risk for perioperative hypoxemia and postoperative pulmonary complications. Pediatric physicians are still reluctant to accomplish low FiO2 strategies in children. We investigated the association between lung ultrasound score (LUS) and arterial oxygenation (PaO2/FiO2 ratio)in anesthetized mechanically ventilated children undergoing non-abdominal surgery using different FiO2 fractions.
Study design: Observational cohort**.**
Study settings: Operative rooms and post-anesthesia care unit**.**
Patients: Thirty-three patients aged (3–12 years) of both sexes.
Intervention: Patients were anesthetized while receiving high FIO2 protocol (preoxygenation 1.0, induction and recovery 0.8, maintenance 0.6, post-extubation 1.0 and 0.21 for 2h postoperative).
Measure: ments: LUS was performed after intubation and initiation of mechanical ventilation, after the end of surgery, and 2h postoperatively. Arterial blood gas analysis was performed at the same time points and respiratory mechanics were recorded intraoperatively. LUS scores were tested for probability of bivariate correlation with PaO2/FiO2 ratio (primary endpoint), age, weight, operation time, PaO2, and dynamic compliance.
Main results: After intubation, the median LUS score was 2 (Range: 0–14) which significantly decreased after surgery to 1 (0–8), (P = 0.010). At 2- hours postoperatively, it was 0 (0–6) which was significantly lower than both after intubation (P = 0.001) and after surgery (P = 0.007). No significant Correlation was found between the LUS score and any investigated parameters.
Conclusions: Even though we found no significant correlation between LUS and PaO2, or PaO2/FiO2 ratio, the high values of LUS after intubation necessitate caution when administering high FiO2 levels in pediatrics.
Trial registration: ClinicalTrials.gov ID: NCT04581226.

1. Introduction

High inspired oxygen concentrations (FiO2 0.8) during and after operative procedures have been recently recommended [1,2]. The clue is that these higher fractions might reduce the incidence of surgical site infections [3]. However, high FiO2 strategies have many drawbacks. First, it may generate reactive oxygen species leading to oxidative stress and DNA damage [4]. Second, the use of high FiO2 during induction and recovery is the most common cause of resorption atelectasis [5]. The rapid absorption of oxygen and loss of the splinting effect of nitrogen is the cause of such a phenomenon [4,5].

Intraoperative lung collapse and atelectasis reduce lung compliance and worsen oxygenation indices in the perioperative period increasing the incidence of postoperative pulmonary complications (PPCS) with

Abbreviations: LUS, Lung ultrasound; FiO2, Fraction of inspired oxygen; FRC, Functional residual capacity; PaO2, Arterial partial pressure of Oxygen; PaO2/FiO2, Ratio of Arterial partial pressure of Oxygen to the inspired oxygen fraction; PEEP, Positive end-expiratory pressure; RM, Recruitment maneuver; C-dyn, Dynamic compliance; a/A ratio, Arterial Alveolar oxygen ratio; A-a DO2, Alveolar-Arterial oxygen gradient.

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higher morbidity and mortality [6,7]. Judicious use of FiO2 concentrations during induction and recovery of anesthesia (FiO2 0.8) with low concentrations during maintenance (FiO2 0.35) have been investigated in many research studies [8–10].

Pediatric physicians are still reluctant to accomplish low FiO2 strategies in children with a large debate on this concept. Children are more prone to the development of atelectasis because of their more compliant chest wall necessitating a low FiO2 strategy [5]. Meanwhile, they are more prone to hypoxemia and desaturation because of their smaller functional residual capacity, higher metabolic rates, and increased incidence of difficult airway management necessitating a high FiO2 strategy to increase the margin of safety in this vulnerable population [11]. The consequences of using high FiO2 in children are not fully investigated.

Ultrasonography is a radiation-free, bedside noninvasive tool that has recently enabled physicians to diagnose intraoperative atelectasis and to guide the alveolar recruitment maneuvers commonly performed to open lung alveoli with high sensitivity and specificity [12,13].

This study aimed to evaluate the effect of high FiO2 on the development of intraoperative atelectasis in mechanically ventilated children using lung ultrasound (LUS) and to investigate the association between the LUS aeration score and the patient's clinical variables and oxygenation indices. The primary endpoint was the correlation between the LUS score and the arterial oxygenation (PaO2/FiO2 ratio). The secondary endpoints were the pulmonary mechanics, arterial blood gas analysis, and perioperative respiratory complications.

2. Patients and methods

2.1. Ethical consideration

After approval by our local institutional ethics committee, faculty of Medicine Assiut University (ID:1710120, date: 21-9-2021), and registration in a clinical trial registry (ClinicalTrials.gov ID: NCT04581226), this prospective observational cohort was conducted in the Pediatric hospital, Assiut university, Assiut, Egypt. This cohort study adhered to the applicable STROBE (Strengthening the reporting of observational studies in epidemiology) guidelines and to the regulations and amendments of the Helsinki Declaration. Written informed consent was taken from the patient's legal guardians.

2.2. Patients

Included in this cohort study were children aged 3–12 years, of both genders, ASA I-II who were scheduled for elective non-abdominal and non-thoracic surgery under general anesthesia with mechanical ventilation of >2h duration. Patients with thoracic deformities, pre-existing lung disease, abnormal preoperative baseline chest US, or preoperative chest infection were excluded from this study.

2.3. Anesthesia, monitoring, and ventilation

Children were pre-oxygenated for 3 min with 100 % oxygen via facemask and baseline routine monitoring was attached. The anesthetic protocol was standardized and consisted of inhalational induction with sevoflurane 8 % in 80 % Oxygen/Air mixture followed by intravenous cannulation then the administration of 0.5 mg/kg lidocaine, 2–3 mg/kg propofol if needed, 1 μg/kg fentanyl and *Cis*-atracurium 0.3 mg/kg for muscle relaxation. A cuffed tracheal tube of appropriate size was inserted, and patients were connected to the ventilator in a volume-control mode. The selected ventilation parameters were 8 ml/kg tidal volume, 5 cmH2O PEEP, 1:1.5 an inspiratory expiratory ratio, 15–25 breaths per minute respiratory rate depending on the age of the child and to maintain end-tidal CO2 at 35–45 mmHg (4.5–6 KPa). Respiratory mechanics were recorded from the anesthesia ventilator machine at 1min. after intubation, and at the end of surgery. These included the exhaled Tidal Volume, exhaled minute ventilation, Peak inflation pressure, mean pressure, and dynamic compliance (calculated as Cdyn = Exhaled TV/(PIP-PEEP) [14]. Anesthesia and muscle relaxation were maintained with 2–3% MAC sevoflurane and *Cis*-atracurium 0.15 mg/kg. An arterial cannula was inserted for the withdrawal of arterial blood samples to determine the pH, PaO2, PaCO2, and arterial oxygen saturation (Radiometer ABL 510 blood-gas analyzer, Copenhagen, Denmark). The samples were withdrawn at 1min. after intubation, at the end of surgery, and 2 h postoperatively. Intravenous paracetamol 1.5 mg/kg (Perfalgan®, Bristol Meyers Squibb, New York) and nalbuphine 0.1 mg/kg iv at the end of the operation for pain management. Intraoperative fluid intake was maintained according to Holiday and Segar's formula using a balanced pediatric formula or normal saline solution. At the end of surgery and before the reversal of muscle relaxation, LUS was done, and its score was recorded. Afterward, a recruitment maneuver under sonographic guidance was performed to ensure the adequate reversal of anesthesia-induced atelectasis before starting patient recovery. The recruitment maneuver was performed in a pressure-controlled mode with 15 cmH2O constant driving pressure and PEEP increments (from 5 to 15 cmH2O) in steps of 5 cmH2O every three successive breaths. A target recruitment pressure of 30 cmH2O was maintained for 10 breaths (~30 s) [14]. The standard ventilatory settings mentioned above including PEEP 5 cmH2O were resumed for 3 min to keep the alveoli open after the lung recruitment. Then the patient was disconnected from the ventilator and muscle relaxation was evaluated and reversed with standard doses of IV atropine and neostigmine. Hemodynamic instabilities such as a ≥20 % decrease in the baseline mean arterial blood pressure during or after the recruitment maneuver were managed and recorded. The LUS performed during the recruitment maneuver was performed to guide the recruitment maneuver, and its scores were not fatherly recorded. Extubation was performed awake in the operative theatre after full reversal of muscle relaxation. Patients were observed for 2 h in the post-anesthesia care unit (PACU) with pulse oximetry and for a further 24 h in the ward. Any perioperative adverse effects including hypotension, arterial oxygen desaturation ≤95 %; pneumothorax, or other respiratory adverse events were treated and recorded.

2.4. Study protocol

2.4.1. FiO2 protocol

The various concentrations of oxygen delivered to the patients are listed in the following sequence: During preoxygenation (FiO2 was set at 1.0 (100 % O2) for 3 min), and During Mask induction (FiO2 was reduced to 0.8). After tracheal intubation and throughout the operative procedure (FiO2 was adjusted to 0.6). After the reversal of muscle relaxation before extubation (FiO2 was set at 0.8). After extubation, patients received an oxygen mask with 100 % oxygen a few minutes before transportation to the PACU. In the PACU, patients received oxygen through a face mask at 5L/min. till full recovery then remain in the PACU on room air till the performance of the postoperative LUS examination 2h postoperatively. The P/F ratio (PaO2/FiO2, normal values: ~400–500 mmHg or ~55–65 kPa) was reported in the same time points mentioned above for arterial blood gas analysis.

2.4.2. Lung ultrasound (LUS)

Preoperatively a preliminary lung US was performed on all patients and patients with abnormal findings were excluded from the study. Three LUS examinations were performed in patients who were enrolled in the study at 1min. after intubation and initiation of mechanical ventilation, at the end of surgery before reversal of muscle paralysis, and at 2 h postoperative.

All the LUS scans we performed under the guidance of an experienced radiologist while our patients were in the supine position with a linear probe of 6–12 MHz of Micromax portable device (Sonosite, Bothell, Washington, USA). Each hemithorax was divided into 6 regions by 3 longitudinal lines (parasternal, anterior, and posterior axillary lines) and 2 axial lines (one above the diaphragm and one 1 cm above the nipples). At first, a complete hemithorax scan was performed with the US probe placed perpendicular to the ribs to identify normal and abnormal findings such as the bat sign, Lung sliding, A-lines, B lines, and air bronchogram [15]. Second, each region was scanned thoroughly, and the degree of lung aeration was recorded using the LUS aeration score [15]. It is a four-point scale of 0–3 (0 = Normal aeration (N) with the presence of lung sliding, A-lines with 1 or 2 B-lines, 1 = Moderate loss of lung aeration (B1): multiple and well-defined B lines, 2 = severe loss of lung aeration (B2): multiple coalescent B-lines that occupy the whole lung image (white lung) and 3 = Complete loss of aeration (C) with Anesthesia-induced atelectasis defined as localized sonographic consolidation (sub-pleural tissue-like pattern). Anesthesia-induced atelectasis is considered significant if any scanned region has a LUS aeration score of ≥2. The sum of the points obtained in all 12 lung areas defines the LUS aeration score of the whole thorax (Range of 0–36). Any additional abnormal findings were also recorded such as pneumothorax or pleural effusion.

2.5. Statistical analysis

2.5.1. Power of the study

This study was hypothesized to investigate the association between lung consolidation score and the clinical patient variables and oxygenation indices. The primary endpoint was to investigate the correlation between the LUS score and the arterial oxygenation (P/F ratio). The sample size was calculated by G Power 3.1.9.7 using a Priori analysis with t-tests- Bivariate Correlation, two-tailed α-error of 0.05, correlation p H1 0.5, and an effect size of 0.5 with a confidence interval of 95 %. These assumptions calculated a sample size of 29 patients. Taking into consideration the possible protocol violations, and patients' dropouts of 10 %, we enrolled 33 patients in this cohort.

2.5.2. Data analysis

Statistical analysis was performed by the SPSS statistical software computer program; version 22 (Statistical Package for Social Science). Data were expressed as mean (SD), median (range or interquartile), or number and percentage. The normality of quantitative Continuous data was checked visually by histograms and analytically by the Shapiro–Wilk test. Then, normally distributed data were analyzed by the paired Student's t-test, While the not normally distributed data and ordinal data were analyzed by the Wilcoxon Signed Rank Test. Chi-square was used to analyze the categorical variables and the Fisher Exact test was applied if the ≥20 % of observations in any variable was <5. The associations between lung ultrasound score and age, weight, operative time, PaO2, P/F ratio, and dynamic compliance, were analyzed using the Person correlation test, and Spearman correlation test as appropriate. P-value <0.05 was considered statistically significant.

3. Results

Thirty-five patients were eligible. Postoperative LUS examination was difficult in 2 patients who were excluded. A total of 33 patients were statistically analyzed. The demographic and clinical characteristics of this studied cohort are listed in Table 1.

After intubation, the median LUS was 2 (Range: 0–14) which significantly decreased after surgery to 1 (0–8), (P = 0.010). At 2- hours postoperatively, the median LUS was 0 (0–6) which was significantly lower than LUS after intubation (P = 0.001) and LUS after surgery (P = 0.007), respectively (Fig. 1) (see Fig. 2).

Pulmonary mechanics including the inhaled and exhaled TV, MV, P max, P mean and C dyn. were measured while ventilating the patient, intraoperatively. Two assessment time points were applicable: after intubation and after surgery. No significant differences were observed between these time points in the above-listed mechanics except for the MV which significantly increased after surgery (P = 0.000), (Table 2).

A small significant increase in the mean PH value was recorded at 2-h postoperatively compared with after intubation (P = 0.009) and after surgery (P = 0.003), while the mean HCO3 at 2-h postoperatively was significantly higher than that after intubation (P = 0.000). The oxygenation variables including the mean partial pressure of oxygen and the SPO2% were significantly decreased at 2h postoperatively compared with after intubation and after surgery (P = 0.000), (Table 3). The highest mean P/F ratio was recorded after intubation. The mean P/F ratio significantly decreased after surgery compared to its baseline value (P = 0.000). At 2 h postoperatively, the P/F ratio nearly resumed its baseline value which was significantly higher than that after surgery (P = 0.000), (Table 3).

Table 1
Demographic and baseline data of the studied Cohort.

Baseline data	Study Cohort (n = 33)	
	Number	Percentage (%)
Sex: Male/Female	21/12	63.6 %/36.4 %
Age (years): Median (Range)	6.0 (3.0–11.0)	
Weight (kg):		
Mean ± SD (Range)	18.39 ± 5.07 (9.0–30.0)	
ASA: I/II	33/0	100 %/0 %
Operation:		
Bilateral tendon transfer	2	6.1 %
Bilateral Strayer op.	1	3.0 %
Bilateral osteotomy	1	3.0 %
DDH	7	21.2 %
Double DDH	2	6.1 %
Double osteotomy	2	6.1 %
Ilizarov External Fixator	3	9.1 %
Pelvic osteotomy	2	6.1 %
Soft tissue replacement	4	12.1 %
Telescoping nail	1	3.0 %
Tendon transfer	7	21.2 %
Tendon transfer and osteotomy	1	3.0 %
Operation time (min):		
Mean ± SD (Range)	127.79 ± 18.25 (70–165)	

Data presented as mean (SD), median (ranger, number, and frequencies. ASA; American Society of Anesthesiologists.

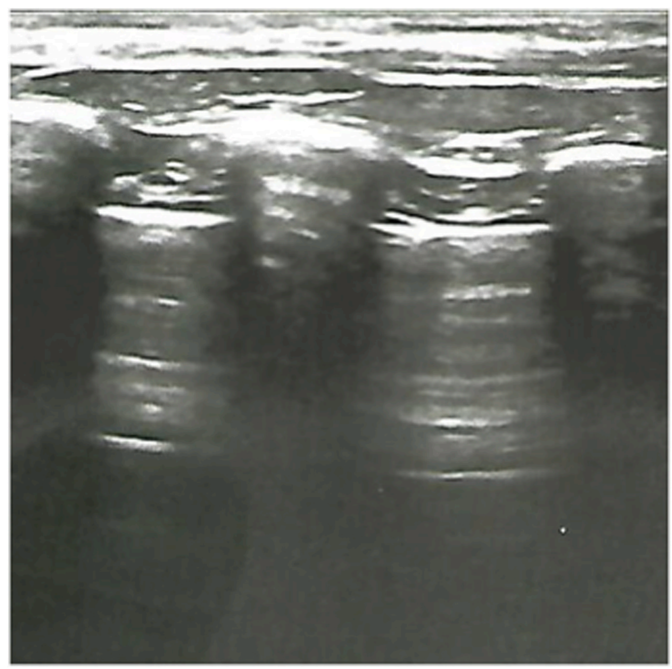

Fig. 1. Figure 1: Lung ultrasound showing normal findings.

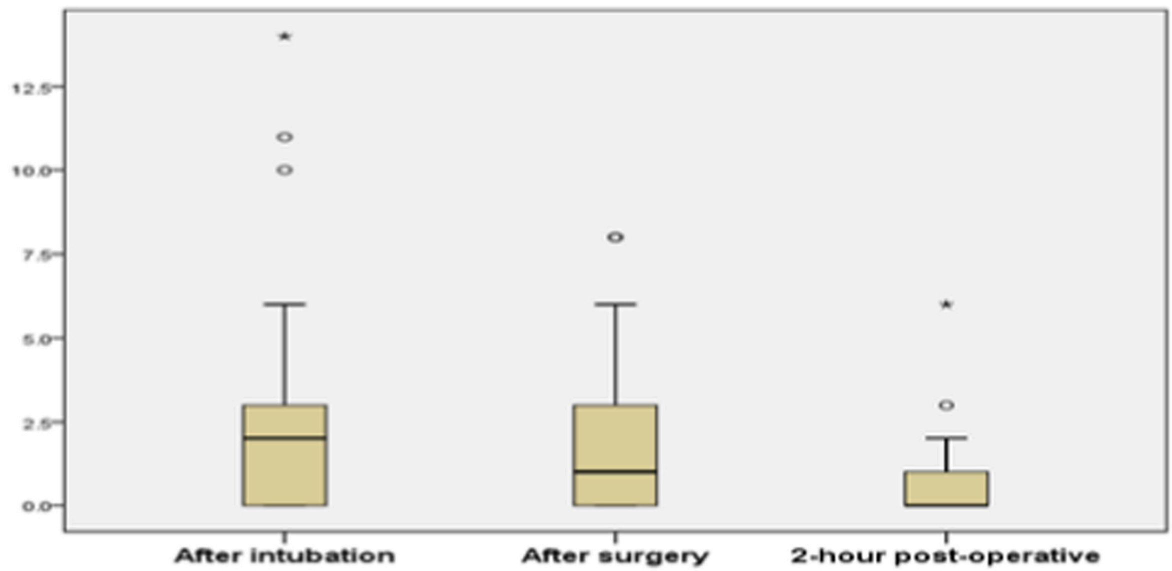

Fig. 2. Figure 2: The Lung Ultrasound Score.

Table 2
Changes in pulmonary mechanics with time.

Study Cohort (n = 33)	After intubation	After surgery	P-value
Inhaled TV:			
Median (Range)	110 (60–250)	120 (70–250)	1.000
Exhaled TV:			
Median (Range)	100 (55–266)	110 (70–230)	0.854
MV:			
Median (Range)	1.7 (0.4–4.4)	1.4 (0.3–3.6)	0.000
Pmax:			
Mean ± SD	15.18 ± 2.56	14.76 ± 2.36	0.367
Range	6.0–19.0	8.0–20.0	
P mean:			
Mean ± SD	5.55 ± 1.66	6.03 ± 1.24	0.174
Range	3.0–11.0	4.0–8.0	
Dynamic compliance (Cdyn):			
Median (Range)	9.2 (4.6–52.5)	10.5 (6.2–25.0)	0.224

Data are presented as mean (SD) and median (range). $P < 0.05$ denotes a significant difference compared with the after-intubation value.

The three recorded time points of lung ultrasound score (after intubation, after surgery, and 2h postoperative) were tested for the probability of correlation with the patient's age, weight, operation time, dynamic compliance, PaO2, and P/F ratio. No significant Correlation was found between the LUS and any of the investigated parameters (Table 4).

4. Discussion

In this study, we investigated the association between LUS score and the clinical patient variables and oxygenation indices in children undergoing non-thoracic non-abdominal surgery under general anesthesia and mechanical ventilation and exposed to different oxygen concentrations during different stations of anesthesia and recovery. The primary endpoint was the correlation between the LUS score and the arterial oxygenation (PaO2/FiO2 ratio). We found that the highest LUS scores were recorded after intubation and the lowest was at 2 h postoperatively. Despite these significant differences, there was no significant correlation between the LUS score and the PaO2/FiO2 ratio either with PaO2, pulmonary compliance, age, weight, or operative duration.

The use of LUS in the intraoperative diagnosis and management of anesthesia-induced atelectasis is promising, being considered a radiation-free, bedside, and noninvasive tool [16]. Despite being subjective and operator-dependent, a good inter-observer agreement has been reported between LUS and MRI for the detection of anesthesia-induced atelectasis [12,16].

In this study, the use of LUS enabled us to demonstrate the effects of different concentrations of oxygen that are commonly used during everyday pediatric anesthesia practice. Despite the well-known hazards

Table 3
Arterial blood gas analysis and PaO2/FiO2 ratio.

Study Cohort (n = 33) ABG	After intubation	After surgery	2-h post-operative
PH:			
Mean ± SD	7.31 ± 0.09	7.31 ± 0.09	7.37 ± 0.08
Range	7.1–7.4	7.1–7.5	7.1–7.6
P-value[1]		0.777	0.009
P-value[2]			0.003
CO_2:			
Mean ± SD	37.44 ± 11.16	40.34 ± 7.52	36.48 ± 7.21
Range	11.8–82.0	26.0–66.0	13.0–44.0
P-value[1]		0.084	0.661
P-value[2]			0.052
PO_2:			
Mean ± SD	249.82 ± 60.31	259.73 ± 51.10	82.70 ± 9.19
Range	142.0–360.0	138.0–330.0	54.1–100.0
P-value[1]		0.313	0.000
P-value[2]			0.000
HCO_3:			
Mean ± SD	19.37 ± 2.78	20.11 ± 2.68	21.21 ± 3.11
Range	11.8–24.9	16.0–25.0	17.0–31.7
P-value[1]		0.194	0.009
P-value[2]			0.089
SpO_2:			
Mean ± SD	99.71 ± 0.48	99.78 ± 0.41	98.88 ± 2.30
Range	98.5–100.0	99.0–100.0	88.0–100.0
P-value[1]		0.326	0.048
P-value[2]			0.031
PaO2/FiO2 ratio:			
Mean ± SD	416.36 ± 100.52	324.66 ± 63.88	393.81 ± 43.78
Range	236.7–600.0	172.5–412.5	257.6–476.2
P-value[1]		0.000*	0.272
P-value[2]			0.000

Data presented as mean (SD). $P < 0.05$ denotes a significant difference. P1: significant difference compared with after-intubation value. P2: significant difference compared with after-surgery value.

Table 4
Correlation testing of Lung Ultrasound Score.

	Lung Ultrasound Score					
	After intubation		After surgery		2-h post-operative	
	r-value	P-value	r-value	P-value	r-value	P-value
Age (years)	0.196	0.273	0.202	0.260	0.168	0.351
Weight (kg)	0.236	0.186	0.196	0.276	0.169	0.346
Operation time (min)	0.159	0.377	0.339	0.054	0.122	0.501
PaO_2:						
After intubation	0.098	0.588	−0.143	0.426	−0.016	0.932
After surgery	0.043	0.813	0.195	0.276	0.078	0.665
2-h post-operative	−0.026	0.887	0.040	0.826	0.154	0.391
P/F ratio:						
After intubation	0.098	0.588	−0.143	0.426	−0.016	0.932
After surgery	0.043	0.813	0.195	0.276	0.078	0.665
2-h post-operative	−0.026	0.887	0.040	0.826	0.154	0.391
Dynamic Compliance:						
After intubation	0.105	0.561	0.112	0.535	0.258	0.147
After surgery	−0.022	0.902	0.186	0.300	0.084	0.643

Data for correlation testing are presented as r-value and P-value. $P < 0.01$ denotes a statistically significant correlation.

of high FiO2 levels, clinicians continuously use these high levels in children. The clues to this approach are that children are at a higher risk for hypoxemia and desaturation because of the lower functional residual capacity and higher metabolic needs than adults [9]. This makes the development of anesthesia-induced atelectasis in children an inevitable anesthesia drawback [9,11].

In this study, the LUS highest scores were recorded at 1 min after intubation and the initiation of mechanical ventilation (median and range: 2, range: 0–14). This coincided with previous studies that reported the occurrence of significant lung collapse after induction of general anesthesia and muscle relaxation [4,5,9]. The LUS score at the end of surgery significantly decreased compared with that after intubation but still showed evidence of atelectasis in some regions (median and range: 1 (0–8), (P = 0.010). This also coincides with the concept that the use of PEEP without recruitment maneuver partially reverses atelectasis [17–19]. In this study, we performed a recruitment maneuver under sonographic guidance after recording our second US scan and before starting patient recovery. Indeed, this is what clinicians do in real settings. Despite that, our third LUS score recorded at 2h postoperatively showed residual atelectasis (median and range: 0 (0–6) which was significantly lower than LUS after intubation (P = 0.001) and LUS after surgery (P = 0.007), respectively. Lee JH et al., in their study, investigated the effects of recruitment maneuvers guided by the US on atelectasis formation and clinical outcomes in children in comparison with the conventional recruitment maneuver. Similar to our results, they found that the US-guided recruitment maneuver was more efficient in the prevention of intraoperative anesthesia-induced atelectasis and desaturation postoperatively, but it did not affect the incidence of postoperative atelectasis [20].

Wu L et al., concluded that LUS enables the early postoperative evaluation of atelectasis and lung aeration, and as mentioned above the degree of atelectasis and lung aeration are closely associated with postoperative oxygenation [21]. The use of LUS in the diagnosis and assessment of postoperative atelectasis is not fully investigated and further studies are needed. A major limitation of this technique in children is their compliance with the examination when they are awake. In this study, we could not examine 2 children because of their poor compliance.

The PaO2/FiO2 ratio is a simple measure of oxygenation that is commonly used in anesthesia and intensive care. It has been used as a surrogate marker for perioperative anesthesia-induced atelectasis [22]. Previous studies reported a strong negative correlation between the LUS score and PaO2/FiO2 ratio in children and adults in different clinical scenarios [23–25].

In this study, we found significant changes in the PaO2/FiO2 ratio with time and with changes in the FiO2 levels administered to our patients. However, in contrast with these studies, we did not find a significant correlation between LUS and PaO2/FiO2 ratio at any investigated time point. Despite being simple to calculate and a good risk stratification tool [26,27], the PaO2/FiO2 ratio is unable to discriminate between different types of hypoxias and is unable to discriminate whether hypoxia is due to decreased FiO2 (normal alveolar-arterial gradient) or hypoventilation (V/Q mismatch with high alveolar-arterial gradient as in atelectasis), insensitive to changes in the atmospheric pressure and is dependent on barometric pressure. The use of the PaO2/FiO2 ratio or the PaO2 for evaluating the degree of atelectasis or to correlate with LUS score in children with healthy lungs may not be accurate or sensitive. The use of Oxygenation indices that depend on alveolar-arterial gradient might have been more sensitive such as the A-a gradient, a/A Ratio, or shunt fraction [27,28]. These physiological facts might explain our results. The healthy pediatric population, small sample size, and the moderate duration of anesthesia in this study may be another explanation.

In this study, we did not report respiratory complications or adverse events postoperatively. However, we did not follow our patients for long periods. In this study, the postoperative LUS score showed atelectasis in some lung regions, however, the overall total score was low (range 0–6). Szabó M et al. reported in their study that the incidence of postoperative pulmonary complications (PPCS) increases with scores higher than 12 (IQR 7–18), this might explain why we did not report PPCS in this study [7].

This study has some limitations, The first is the small sample size. A larger sample could have strengthened our results. Second is the use of the PaO2/FiO2 ratio as the sole index for oxygenation. This is because the PaO2/FiO2 cannot differentiate between different causes of hypoxia. Further studies in this topic using more sensitive indices of oxygenation such as the A-a gradient, a/A Ratio, or shunt fraction are needed. Third is the short postoperative follow-up period. As mentioned above, a longer postoperative follow-up period was necessary to trace the occurrence of postoperative pulmonary complications in patients who developed anesthesia-induced-atelectasis.

In conclusion, the high FiO2 levels used in this study and the recruitment maneuver done at the end of the operation are the techniques that are typically used in real settings in everyday pediatric anesthesia practice. Despite there being no significant correlation between the LUS and the PaO2, or PaO2/FiO2 ratio, the high values of LUS after intubation necessitate caution when administering high FiO2 levels in the pediatric population. Further studies of a larger sample size and longer postoperative follow-up duration are needed to confirm or declare our findings.

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CRediT authorship contribution statement

Hala Saad Abdel-Ghaffar: Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Hala Mahmoud Sayed Abdelaal:** Writing – original draft, Methodology. **Mohamed Adel Abdelkareem:** Visualization, Methodology. **Sara Mahmoud Ahmed Hassanein:** Methodology. **Yara Hamdy Abbas:** Writing – original draft, Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no competing interest.

References

[1] B. Allegranzi, P. Bischoff, S. de Jonge, et al., New WHO recommendations on preoperative measures for surgical site infection prevention: an evidence-based global perspective, Lancet Infect. Dis. 3099 (2016) 1–16.

[2] S.I. Berrı`os-Torres, C.A. Umscheid, D.W. Bratzler, et al., Centers for Disease Control and Prevention guideline for the prevention of surgical site infection, 2017, JAMA Surg 152 (2017) 784–790.

[3] M.B. Cohen, M.K. Ruetzler, A. Kurz, S. Leung, E. Rivas, J. Ezell, G. Mao, Sessler, D. A. Turan, Intra-operative high inspired oxygen fraction does not increase the risk of postoperative respiratory complications Alternating intervention clinical trial, Eur. J. Anaesthesiol. 36 (2019) 320–326.

[4] B. Grandville, F. Petak, G. Albu, S. Bayat, I. Pichon, W. Habre, High inspired oxygen fraction impairs lung volume and ventilation heterogeneity in healthy children: a double-blind randomised controlled trial, Br. J. Anaesth. 122 (5) (2019) 682e691.

[5] L. Magnusson, D.R. Spahn, New concepts of atelectasis during general anaesthesia, Br. J. Anaesth. 91 (2003) 61e72.

[6] A. Miskovic, A.B. Lumb, Postoperative pulmonary complications, Br. J. Anaesth. 118 (3) (2017 Mar 1) 317–334, https://doi.org/10.1093/bja/aex002.PMID:28186222.

[7] M. Szabó, A. Bozó, K. Darvas, S. Soós, M. Őzse, Z.D. Iványi, The role of ultrasonographic lung aeration score in the prediction of postoperative pulmonary complications: an observational study, BMC Anesthesiol. 21 (1) (2021 Jan 14) 19, https://doi.org/10.1186/s12871-021-01236-6. PMID: 33446103; PMCID: PMC7807225.

[8] I.-K. Song, Y.-E. Jang, J.-H. Lee, et al., Effect of different fractions of inspired oxygen on development of atelectasis in mechanically ventilated children: a randomized controlled trial, Pediatr Anesth 29 (2019) 1033–1039.

[9] H.I. Kim, J.Y. Min, J.R. Lee, C. Kwan Woong, M.R. Cho, H.J. Byon, The effect of oxygen concentration on atelectasis formation during induction of general anesthesia in children: a prospective randomized controlled trial, Paediatr. Anaesth. 31 (12) (2021 Dec) 1276–1281, https://doi.org/10.1111/pan.14304. Epub 2021 Oct 11. PMID: 34614266.

[10] J.B. Martin, D. Garbee, L. Bonanno, Effectiveness of positive end-expiratory pressure, decreased fraction of inspired oxygen and vital capacity recruitment maneuver in the prevention of pulmonary atelectasis in patients undergoing general anesthesia: a systematic review, JBI Database System Rev Implement Rep 13 (8) (2015 Sep 16) 211–249, https://doi.org/10.11124/jbisrir-2015-1410. PMID: 26455945.

[11] J.E. Morrison Jr., Children at increased risk of hypoxia, Anesthesiology 92 (6) (2000) 1844.

[12] C.M. Acosta, G.A. Maidana, D. Jacovitti, et al., Accuracy of transthoracic lung ultrasound for diagnosing anesthesia-induced atelectasis in children, Anesthesiology 120 (2014) 1370–1379.

[13] I.K. Song, E.H. Kim, J.H. Lee, S. Ro, H.S. Kim, J.T. Kim, Effects of an alveolar recruitment manoeuvre guided by lung ultrasound on anaesthesia-induced atelectasis in infants: a randomised, controlled trial, Anaesthesia 72 (2017) 214e22.

[14] C.M. Acosta, T. Sara, M. Carpinella, G. Volpicelli, L. Ricci, S. Poliotto, D. Abrego, S. Gonorazky, S.H. Böhm, G. Tusman, Lung recruitment prevents collapse during laparoscopy in children: a randomized controlled trial, Eur. J. Anaesthesiol. (2017 Dec 22).

[15] A. Soummer, S. Perbet, H. Brisson, C. Arbelot, J.M. Constantin, Q. Lu, J.J. Rouby, Lung Ultrasound Study Group, Ultrasound assessment of lung aeration loss during a successful weaning trial predicts postextubation distress, Crit. Care Med. 40 (7) (2012 Jul) 2064–2072, https://doi.org/10.1097/CCM.0b013e31824e68ae. PMID: 22584759.

[16] M.A. Cecilia, A.M. Gustavo, J. Daniel, B. Agustín, C. Silvana, R. Elizabeth, M. Ananda, G. Sergio, H.B. Stephan, T. Gerardo, Accuracy of transthoracic lung ultrasound for diagnosing anesthesia-induced atelectasis in children, Anesthesiology 120 (June 2014) 1370–1379.

[17] H.U. Rothen, P. Neumann, J.E. Berglund, J. Valtysson, A. Magnusson, G. Hedenstierna, Dynamics of re-expansion of atelectasis during general anaesthesia, Br. J. Anaesth. 82 (4) (1999 Apr) 551–556, https://doi.org/10.1093/bja/82.4.551.PMID:10472221.

[18] L. Wu, Q. Hou, J. Bai, J. Zhang, L. Sun, R. Tan, M. Zhang, J. Zheng, Modified lung ultrasound examinations in assessment and monitoring of positive end-expiratory pressure-induced lung reaeration in young children with congenital heart disease under general anesthesia, Pediatr. Crit. Care Med. 20 (5) (2019 May) 442–449, https://doi.org/10.1097/PCC.0000000000001865. PMID: 31058784.

[19] T. Dyhr, E. Nygård, N. Laursen, A. Larsson, Both lung recruitment maneuver and PEEP are needed to increase oxygenation and lung volume after cardiac surgery, Acta Anaesthesiol. Scand. 48 (2) (2004 Feb) 187–197, https://doi.org/10.1111/j.0001-5172.2004.00300.x.PMID:14995941.

[20] J.H. Lee, S. Choi, S.H. Ji, Y.E. Jang, E.H. Kim, H.S. Kim, J.T. Kim, Effect of an ultrasound-guided lung recruitment manoeuvre on postoperative atelectasis in children: a randomised controlled trial, Eur. J. Anaesthesiol. 37 (8) (2020 Aug) 719–727, https://doi.org/10.1097/EJA.0000000000001175. PMID: 32068572.

[21] L. Wu, Y. Yang, Y. Yin, L. Yang, X. Sun, J. Zhang, Lung ultrasound for evaluating perioperative atelectasis and aeration in the post-anesthesia care unit, J. Clin. Monit. Comput. (2023 Mar 24), https://doi.org/10.1007/s10877-023-00994-7. Epub ahead of print. PMID: 36961634.

[22] A.M. Yıldız, G. Kılınç, H. Sungurtekin, S. Karaduman, O. Birsen, Impact of positive end-expiratory pressure with alveolar recruitment maneuver on respiratory and oxygenation parameters of patients during laparoscopic bariatric surgery, Eur. Rev. Med. Pharmacol. Sci. 26 (24) (2022 Dec) 9170–9179, https://doi.org/10.26355/eurrev_202212_30668.PMID:36591829.

[23] M. Elayashy, M.A. Madkour, A.A.A. Mahmoud, H. Hosny, A. Hussein, A. Nabih, A. Lofty, H.M. Hamza, P. Hassan, M. Wagih, A.K. Mohamed, Effect of ultrafiltration on extravascular lung water assessed by lung ultrasound in children undergoing cardiac surgery: a randomized prospective study, BMC Anesthesiol. 19 (1) (2019 Jun 4) 93, https://doi.org/10.1186/s12871-019-0771-1. PMID: 31159739; PMCID: PMC6547534.

[24] P. Todur, Souvik Chaudhuri FNB critical care; Vedaghosh Amara FNB critical care; Srikant N, Prakash P., Correlation of oxygenation and radiographic assessment of lung Edema (RALE) score to lung ultrasound score (LUS) in acute respiratory distress syndrome (ARDS) patients in the intensive care unit, Can. J. Respir. Ther. 57 (2021 May 19) 53–59, https://doi.org/10.29390/cjrt-2020-063. PMID: 34041358; PMCID: PMC8132988.

[25] W. Yin, T. Zou, Y. Qin, J. Yang, Y. Li, X. Zeng, Y. Kang, Chinese Critical Ultrasound Study Group (CCUSG). Poor lung ultrasound score in shock patients admitted to the ICU is associated with worse outcome, BMC Pulm. Med. 19 (1) (2019 Jan 3) 1, https://doi.org/10.1186/s12890-018-0755-9. PMID: 30606165; PMCID: PMC6318853.

[26] R.R. McNeer, Modeling the impacts of assumptions and nonpulmonary factors on the performance and reliability of indices of oxygenation, J. Clin. Monit. Comput. (2023 Apr 13), https://doi.org/10.1007/s10877-023-00997-4. Epub ahead of print. PMID: 37052615.

[27] A. Coetzee, J. Swanevelder, G. van der Spuy, J. Jansen, Gas exchange indices–how valid are they? S. Afr. Med. J. 85 (11 Suppl) (1995 Nov) 1227–1232. PMID: 8914565.

[28] P.J. Hantzidiamantis, E. Amaro, Physiology, alveolar to arterial oxygen gradient. 2022 Jun 6, in: StatPearls [Internet]. Treasure Island (FL), StatPearls Publishing, 2023 Jan. PMID: 31424737.