International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

Effect of sustained inflations on lung atelectasis during paediatric laparoscopic surgery as determined by lung ultrasound, a randomized controlled trial

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Abstract

Atelectasis is among the most frequent postoperative pulmonary complications of general anesthesia and can be observed in all types of surgery and age groups. Various methods of lung recruitment have been studied in paediatrics but typically involve either sustained inflations or manipulating positive end expiratory pressure. Lung ultrasound is a reliable and accurate non-invasive tool for detecting anaesthesia induced atelectasis. The aim of our study is to assess the beneficial effect of sustained inflations as a recruitment maneuver on the degree of lung atelactasis that occurs in paediatric patients undergoing laparoscopy surgery as assessed by lung ultrasound examination. Forty patients aged 1-6 years were included, randomized to either a recruitment group or a control group. Anaesthesia was induced with sevoflurane using a Mapleson E circuit. Lungs were ventilated in a volume controlled mode using FiO2 0.5, Tidal volume 6 ml/kg, PEEP 5 cmH20, an inspiratory: expiratory ratio 1:2, respiratory rate between 20 and 30 breaths per minute to maintain end tidal CO2 between 30-35 mmHg. A sustained inflation was performed immediately after the second lung ultrasound examination and was repeated every 20 minutes during the period of capnoperitoneum. Patients were studied before capnoperitoneum (5 minutes after induction of anaesthesia), during capnoperitoneum (10 minutes after starting capnoperitoneum) and after capnoperitoneum (5 minites after the end of surgery before discontinuation of anaesthesia and extubation). Lung ultrasound was done by linear multi frequency 6-13 MHz probe. Four lung ultrasound patterns were defined according to the degree of B lines (0) fewer than three isolated B lines (1) multiple well defined B lines (2) multiple coalescent B lines and (3) white lung. Incidence of significant ling atelectasis is defined as the presence of a score of greater than or equal to 2 in any of the 12 lung regions. Results and discussion: 40 patients (26 males/14 females) aged 4.0+/-1.6 in control group and 4.2+/-1.7 in the recruitment group, weighing 16.9+/-3.7 in the control group and 18.0+/-3.9 in the recruitment group were studied. The incidence of atelectasis after capnoperitoneum was lesser in the recruitment group (35%) compared to the control group (60%). No significant difference between both groups was found. The main finding in our study was that applying sustained inflations as a recruitment maneuver every 20 minutes followed by a PEEP of 8 cmH20 in paediatrics patients undergoing laparoscopic surgery improved the total lung aeration score compared to baseline scores. This was proved by calculating a delta score. The recruitment group showed a greater degree of improvement in the total lung aeration score compared to the control group (p value less than 0.001). The number of patients in the recruitment group that had a decrease in total lung aeration score after capnoperitoneum relative to their baseline total lung aeration score were 10 out of 20 while only 3 patients improved in the control group. A significant p value of 0.04 was found in the number of patients whose total lung aeration score improved after capnoperitoneum between both groups. The mean lung aeration score in the control group after capnoperitoneum increased (3.9) compared to before (2.3) while the mean lung aeration score decreased after capnoperitoneum (2.5) compared to before (3.4) in the recruitment group. However no significant difference was found between both groups. The recruitment maneuver was well tolerated hemodynamically and was not stopped in any of the patients. All cardiovascular variables, peak and plateau inspiratory pressures remained within normal values. There was no incidence of oxygen desaturation or othe complications in any of our patients. The clinical implication of our findings is that recruitment maneuvers can reduce the amount of lung collapse induced by the deleterious combination of general anaesthesia and capnoperitoneum. Further studies should consider the use of real time sonography along with a PEEP titration trial during laparoscopic procedures in paediatric patients to accurately ensure no collapsed lung areas are detected.

Keywords: sustained inflations, recruitment maneuver, lung atelectasis, paediatric laparoscopic surgery, lung ultrasound.

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1. Introduction

Atelectasis is among the most frequent postoperative pulmonary complications of general anaesthesia and can be observed in all types of surgery and all age groups [1]. Atelectasis impairs gas exchange, thus causing hypoxemia and likely other respiratory disorders such as acute lung injury and pneumonia. Researchers found that atelectasis occurs in a majority of children undergoing general anaesthesia, with an incidence of between 68% and 100% [2-4]. Younger children, particularly infants, are vulnerable to hypoxemia due to their smaller functional residual capacity and increased metabolic requirements compared with adults [5]. By approximately two years of age, chest wall and lung compliance are similar to adults. However, older infants and children continue to have significantly smaller airway radius in proportion to their weight, less elastic retraction force, and a lower relaxation volume. These factors all combine to predispose infants and children to atelectasis and hence an increased risk of Ventilator Induced Lung Injury (VILI) [6]. Capnoperitoneum induced during laparoscopy may aggravate lung collapse as it generates a further increase in intra-abdominal pressure [7]. Because the chest wall and abdomen work in series, impairment of abdominal compliance induced by capnoperitoneum may significantly influence thoracic compliance, causing changes in pleural pressure [8]. Neonates, infants and small children have in common low functional residual capacity, high pulmonary closing capacity and high oxygen consumption, and are especially prone to develop atelectasis and hypoxemia during laparoscopic procedures [9-10].

Subsequently these populations show potential to benefit most from alveolar recruitment manoeuvres. However, data on when, for how long, how often and exactly how to apply these strategies in children are limited. Various methods of lung recruitment have been studied in paediatrics but typically they involve either sustained inflations or manipulating positive end expiratory pressure (PEEP). Sustained inflations (SI) or inspiratory holds recruit alveoli via a combination of factors – the plateau pressure achieved, and the duration of time maintained at that pressure. SI's are reported within literature as ranging from 25-60 cmH_2O and held for a period of 10-30 seconds. Irrespective of the technique used, the purpose of the SI is to maintain an elevated plateau pressure for a period of time greater than that achieved with tidal breathing [6]. Lung ultrasound (LUS) is a reliable and accurate non-invasive imaging tool for detecting anaesthesia-induced atelectasis [11]. LUS has great potential for bedside assessment and monitoring of lung aeration particularly when the effect of a therapeutic intervention is assessed [12-13]. It is a tool that appears suitable for use with children for observing changes in lung aeration during laparoscopy [14].

2. Materials and Methods

2.1. Methodology

This prospective double-blinded randomized controlled clinical trial was conducted in the paediatric operative theatre at Abo El Reech Hospital, Faculty of Medicine, Cairo University. After obtaining approval form the Ethics and Research Committee (Code: MD-240-2021) and protocol registration on clinical trials.

Gov, forty paediatric patients performing moderate abdominal laparoscopic surgery between (October) 2021 and (December) 2022, were included in the study after obtaining an informed consent from the child's legal guardian/parent. The patients were randomly allocated into one of the two study groups: 20 patients per group.

2.2. Eligibility criteria

2.2.1. Inclusion criteria

- Signed Informed Parental Consent
- Age 1-6 years
- Scheduled for moderate abdominal laparoscopic surgery (surgery time averaging between 1-2 hours such as laparoscopic appendectomy, cholecystectomy, undescended testis repair, gonadectomy and ovarian cyst removal).
- American Society of Anaesthesiologists (ASA) physical status classification I-II

2.2.2. Exclusion criteria

- Emergency and thoracic procedures.
- Significant pre-existing lung diseases such as asthma, emphysema, cystic fibrosis, bronchitis, pleural effusion, pneumonia, pulmonary oedema or pneumothorax.
- Significant pre-existing cardiac disorders such as congenital heart defects and pulmonary hypertension.
- Significant pre-existing chest wall deformities such as scoliosis.
- Abdominal distension.
- Previous thoracic procedure

2.3. Study Procedures

2.3.1. Study Protocol

Following approval from ethics and research committee of anaesthesia department, all patients fulfilling the eligibility criteria were enrolled in the study. The patients were randomly allocated by a computer-generated table into one of two study groups: recruitment group (RM) and control group (C). The randomization sequence was concealed in sealed opaque envelopes. An informed signed parental consent was obtained.

2.3.2. Anesthesia

In the preoperative phase, patients were given 0.5 mg/kg of oral midazolam as a premedication 45 minutes prior to induction of anaesthesia. Standard Electrocardiography (ECG), non-invasive blood pressure measurement, time-based capnography and pulse oximetry were used as monitors. Anaesthesia was induced with Sevoflurane using a Mapleson E (modification of Ayre's T-piece) circuit. An Intravenous access was obtained. Fentanyl 2 μg/kg and Atracurium 0.5 mg/kg were administered intravenously before intubation with a cuffed endotracheal tube of appropriate size followed by controlled ventilation. The lungs were ventilated in a volume control mode (VCM) using a FiO_2 of 0.5, a tidal volume of 6 ml/kg, a positive end-expiratory pressure (PEEP) of 5 cmH_2O, an inspiratory:

expiratory ratio of 1:2, respiratory rate between 20 and 30 breaths per minute to maintain end tidal CO_2 between 30-35 mmHg. Anaesthesia was maintained with sevoflurane 2% in the supine position. Top up doses of muscle relaxant were administered as needed. We followed the 4:2:1 rule for maintenance fluids. Deficit (preoperative fluid deficits according to fasting hours), and replacement fluid requirements (crystalloids 3:1 and colloids 1:1) were given. Temperature was closely monitored and maintained by a warming blanket and warming of all intravenous fluids. At the end of surgery, 0.02 mg/kg atropine and 0.05 mg/kg neostigmine were administered to reverse neuromuscular blockade. Extubation was performed when spontaneous breathing was adequate, and the patient was fully awake.

2.3.3. Randomization

The patients were randomly allocated. The randomization sequence was concealed in sealed opaque envelopes. The investigator performing the LUS and the subject's parents were unaware of the group allocation. (Double-blinded study)

- **Control group (C group):** patients received the conventional ventilatory settings as described above. LUS examinations were performed 5 minutes after induction of anaesthesia, 10 minutes after induction of pneumoperitoneum, and 5 minutes after the end of surgery before discontinuation of anaesthesia and extubation.
- **Recruitment group (RM group):** LUS examination was performed 5 minutes after induction of anaesthesia. Ten minutes after induction of capnoperitoneum (not exceeding an intra-abdominal pressure of 6-12 mmHg), a second LUS examination was performed. A Sustained inflation was performed immediately after this LUS examination and was repeated every 20 minutes during the period of capnoperitoneum. Sustained inflations were applied at a pressure of 30 cmH_2O using the Adjusted Pressure Limiting (APL) valve and were held for of 30 secs. After each SI, the standard ventilatory settings were resumed with a PEEP setting of 8 cmH_2O to prevent lung de-recruitment. Lung recruitment was stopped immediately if mean arterial pressure and/or heart rate changed by at least 25% from baseline values. A third LUS examination was performed at the end of surgery before discontinuation of anaesthesia and extubation.

Patients were studied at three points:

1. Before capnoperitoneum: 5 minutes after induction of anaesthesia, baseline recordings were obtained.
2. During capnoperitoneum: measurements were performed 10 minutes after starting the capnoperitoneum.
3. After capnoperitoneum: 5 minutes after the end of surgery before discontinuation of anesthesia and extubation.

2.3.4. Lung Ultrasound

LUS was performed by a single experienced personnel using the SonoSite M Turbo (USA) with a linear multi-frequency 6-13 MHz probe. Each hemithorax was divided into six regions, using three longitudinal lines (parasternal, anterior and posterior axillary) and two axial lines (one above the diaphragm and the other 1 cm above the nipples). The 12 lung regions were scanned sequentially from right to left, cranial to caudal and anterior to posterior. Each region was assessed using a two-dimensional view with the probe placed parallel to the ribs. An aeration score previously described for adults was applied in our paediatric patients [15-16]. Four LUS patterns were defined according to the degree of B lines: (0) fewer than three isolated B lines; (1) multiple well defined B lines; (2) multiple coalescent B lines and (3) white lung. The sum of the points obtained in all the 12 lung areas constituted the lung aeration score, ranging from 0-36 for the whole thorax. This score is inversely proportional to the degree of lung aeration and directly proportional to the degree of lung atelectasis. [14] Incidence of significant lung atelectasis is defined as the presence of a score of ≥2 in any of the 12 lung regions.

2.3.4.1. Measurement tools

- Lung aeration score.
- Hemodynamic parameters: HR, Non-invasive blood pressure, end-tidal CO_2 and oxygen saturation.
- Respiratory mechanical parameters: Peak airway pressure (Paw peak) and plateau pressure (Paw plateau).
- Occurrence of intraoperative pulmonary adverse effects such as pneumothorax or surgical emphysema.
- Occurrence of intraoperative desaturation (SpO_2 <92%) or change in heart rate and arterial blood pressure by at least 25% of baseline values.
- Duration of capnoperitoneum

2.4. Study outcomes

2.4.1. Primary outcome

Incidence of significant lung atelectasis in the LUS examination performed after capnoperitoneum at the end of surgery. Incidence of significant lung atelectasis was defined as the presence of a score of ≥2 in any of the 12 regions.

2.4.2. Secondary outcomes

- The lung aeration score in the predefined time points.
- Incidence of significant lung atelectasis in the other two LUS examinations (before and during capnoperitoneum).
- Correlation between lung aeration score with duration of capnoperitoneum.
- Incidence of hemodynamic instability or oxygen desaturation with the sustained inflation recruitment manoeuvre.
- Incidence of intraoperative complications such as pneumothorax detected by LUS (absence of lung sliding)

2.5. Statistical Analysis

2.5.1. Sample size

Based on the primary outcome, sample size calculation was done using the comparison of incidence of lung collapse between standard ventilation and a lung recruitment manoeuvre in pediatric patients scheduled for abdominal laparoscopic surgery using a four-point aeration score by ultrasound imaging. Calculation was done based on comparing 2 proportions from independent samples in a prospective study using Chi test, the α-error level was fixed at 0.05, the power was set at 80% and the intervention groups ratio was set at 1. As previously published, the incidence of lung collapse among lung recruitment manoeuvre group was 24% while it was 85% in standard ventilation group [14]. Accordingly, the minimum optimum sample size should be 18 participants in each group to detect a real difference of 10% in incidence of lung collapse. Sample size calculation was done using PS Power and Sample Size Calculations software, version 3.0.11 for MS Windows (William D. Dupont and Walton D., Vanderbilt University, Nashville, Tennessee, USA).

2.5.2. Statistical Analysis

Data were statistically described in terms of mean ± standard deviation (mean ± SD), median and range, or frequencies (number of cases) and percentages when appropriate. Numerical data were tested for the normal assumption using Shapiro Wilk test. Comparison of numerical variables between the study groups was done using Mann Whitney *U* test for independent samples. For comparing categorical data, Chi-square ($\chi 2$) test was performed. Exact test was used instead when the expected frequency is less than 5. Comparison of occurrence of atelectasis between before, during and after canpoperitoneum was done using McNemar test after applying Bonferroni adjustment of multiple comparisons. Two-sided *p* values less than 0.05 was considered statistically significant. IBM SPSS (Statistical Package for the Social Science; IBM Corp, Armonk, NY, USA) release 22 for Microsoft Windows was used for all statistical analyses.

3. Results and Discussion

We enrolled 40 patients performing moderate laparoscopic surgery in the paediatric operative theatre at Abo El Reech Hospital, Faculty of Medicine, Cairo University. No patients refused participation, were excluded, or had their data lost through the follow up.

3.1. Incidence of oxygen desaturation or complications

There was no incidence of oxygen desaturation or other complications in any of the patients. The current study discusses the high incidence of lung collapse in anaesthetised children undergoing laparoscopy. The main finding in our study was that applying sustained inflations as a recruitment manoeuvre every 20 minutes followed by a PEEP of 8 cmH2O in paediatric patients undergoing laparoscopic surgery improved the total lung aeration score compared to the baseline scores (before capnoperitoneum) detected by lung ultrasonography.

This was proved by calculating a delta score (difference between the total lung aeration score before and after capnoperitoneum). The recruitment group showed a greater degree of improvement in the total lung aeration score compared to the control group (p value <0.001). Moreover, the number of patients in the recruitment group that had a decrease in total lung aeration score after capnoperitoneum relative to their baseline (before capnoperitoneum) total lung aeration score were 10 out of 20 patients while only 3 patients improved in the control group. The remainder of patients either maintained the same total lung aeration score or worsened. A significant p value (0.04) was found in the number of patients whose total lung aeration score improved after capnoperitoneum between both groups. We defined the incidence of significant lung atelectasis as an aeration score ≥2 in any of the 12 lung regions. The incidence of atelectasis after capnoperitoneum was lesser in the recruitment group (35%) compared to the control group (60%). However, we found no significant difference between both groups. The incidence of significant atelectasis before (50%) and during capnoperitoneum (65%) was more than after capnoperitoneum (35%) in the recruitment group while in the control group, incidence of atelectasis was more during capnoperitoneum (50%) than before (35%) and continued to increase after capnoperitoneum (60%). However no significant difference was found at the different points in each group. The mean lung aeration score in the control group after capnoperitoneum increased (3.9) compared to before (2.3) while the mean lung aeration score decreased after capnoperitoneum (2.5) compared to before (3.4) in the recruitment group. However, no significant difference was found between both groups. This suggests that the negative effects of anaesthesia and capnoperitoneum persisted in paediatric patients that received a standard ventilation strategy with no recruitment manoeuvre applied. With variation of the recruitment manoeuvre applied, most literature agree that applying a recruitment manoeuvre to paediatric patients undergoing laparoscopic surgery significantly improves lung aeration. Acosta et al., found that lung collapse due to capnoperitoneum could be prevented by recruitment manoeuvres followed by positive-end expiratory pressure. The recruitment manoeuvre was performed in a pressure-controlled mode with a constant driving pressure of 15 cmH2O. PEEP was increased in steps of 5 cmH2O, from 5 to 15 cmH2O, every three breaths. The target recruitment pressure of 30 cmH2O was maintained for 10 breaths, corresponding to approximately 30 seconds followed by the standard protective ventilatory settings with 8 cmH2O of PEEP [14]. Our study matches their measurement of the lung aeration score in a 0–3-point score system for 12 lung regions and the incidence of significant lung atelectasis as a score ≥2 in any lung region. Incidence of atelectasis was 80% in the control group compared to 24% in the recruitment group. (p value <0.001). In comparison to our study, their patients aged 6 months to 7 years received a recruitment manoeuvre after baseline recordings and before the induction of capnoperitoneum. Other studies have discussed the effect of recruitment manoeuvres on lung aeration but in non-laparoscopic surgery in other age groups. Song et al., studied 40 patients under 1 year of age performing elective minor surgery [17]. Under ultrasound guidance, a stepwise increase in airway pressure from 10 cmH2O by 5 cmH2O increments with a 0.4 inspired oxygen fraction was applied manually until no collapsed lung areas were visible on ultrasound to a maximum airway pressure of 40 cmH2O. the control group of the other hand received standard ventilation. Two ultrasound images we done; the first 1 minute after mechanical ventilation and the other at the end of surgery. The recruitment manoeuvre was done after each LUS image in the recruitment group. Like our study, they also measured the incidence of significant lung atelectasis (being a score of ≥2 in any of the 12 lung regions). The incidence of lung atelectasis was 25% in the recruitment group compared to 80% in the recruitment group (p value 0.001). This study also studied the distribution of lung atelectasis in the anterior, lateral and posterior regions. Zhu et al., studied 60 patients aged 1-6 years old performing non abdominal surgery (≤2 hours duration) [18]. These patients were randomly allocated in to two groups: zero end expiratory pressure with no recruitment manoeuvre and a lung protective group with a recruitment manoeuvre. Recruitment manoeuvres were performed immediately after induction of anaesthesia, every 30 min intra-operatively, after any disconnection from the ventilator and immediately before tracheal extubation. Recruitment manoeuvres were performed, in pressure-controlled mode, with a constant driving pressure of 15 cmH2O. PEEP was increased in steps of 5 cmH2O, from 5 to 15 cmH2O, every three breaths. The target recruitment pressure of 30 cmH2O was maintained for 10 breaths. LUS images were done after induction, surgery and tracheal extubation, 15 minutes, 3 hours, 12 hours and 24 hours. An aeration score of 0-3 was used in the 12 lung regions. They found that worst aeration score occurred after extubation. The lung protective group had lower aeration scores compared to the no recruitment group, but this effect was not maintained after 15 minutes. Jang et al., performed a recruitment manoeuvre once every hour in 37 children under 3 years of age performing surgery in prone position (real time ultrasound guided alveolar recruitment 30-40 cmH20 for 5-10 seconds until no collapsed lung areas were detected then a PEEP of 7 cmH20 was maintained). They assessed the incidence of significant lung atelectasis (aeration score ≥2 in any lung region) in both groups and a significant difference was found (p<0.0001) suggesting that the incidence was much lower in the recruitment group. LUS has great potential as it represents a radiation-free, non-invasive and reliable tool for assessing lung aeration at the bedside [20-21]. When compared with magnetic resonance imaging, LUS showed high sensitivity (88%), specificity (89%) and accuracy (88%) for diagnosing anaesthesia-induced atelectasis in children [22]. These results were similar to those observed by Yu et al. (111) in anesthetised adults, who showed good sensitivity (87%), specificity (92%) and accuracy (91%) in verifying the occurrence of atelectasis by LUS in comparison with computed tomography (CT)-scan as the reference method. The number of B-lines, well known LUS artefacts related to a deterioration in lung aeration, also correlated with the extent of parenchymal changes on CT scans in children. The LUS aeration score described by Soummer et al., and Bouhemad et al., is a well-established and validated method for evaluating the condition of lung aeration and monitoring its changes over time [12,23].

The same LUS method has already been tested in anaesthetised adults undergoing laparoscopy. A correlation was done between the total lung aeration score after capnoperitoneum and the duration of capnoperitoneum in both groups as shown in table (6). No statistical significance was found in control group. However, a negative correlation (p value 0.045) was established between the total lung aeration score after capnoperitoneum and the duration of capnoperitoneum in the recruitment group. We performed sustained inflations every 20 minutes, abolishing the effect of duration of capnoperitoneum on lung aeration. Lutterbey et al., described a 12% increase in the amount of atelectasis during 85 min of general anaesthesia [3]. Acosta et al., also found that the extension of atelectasis doubled (23%) only 20 minutes after reaching the target capnoperitoneum pressure in the control group but they also found that the development of aeration during the procedures was not affected by the time course of surgery [14]. The recruitment maneuver (repeated sustained inflations) was well tolerated hemodynamically and was not stopped in any of the patients. All cardiovascular variables, peak and plateau inspiratory pressures remained within normal values and showed no significant rise or decline.

There was no incidence of oxygen desaturation or other complications in any of our patients. The clinical implication of our findings in paediatric patients is that a recruitment manoeuvre can reduce the amount of lung collapse induced by the deleterious combination of general anaesthesia and capnoperitoneum. Further studies should consider the use of real time sonography along with a PEEP titration trial during laparoscopic procedures in paediatric patients to accurately ensure no collapsed lung areas are detected. Our study has some limitations. Our study appeared to be underpowered. An increase in the number of patients enrolled would have pointed out a greater significance. The lack of baseline LUS images before induction of anaesthesia. The unlikely compliance of awake children in the stressful situation preceding surgery reduces the feasibility of a routine examination. We assumed that all patients had normal lung aeration before anaesthesia.

3.2. Incidence of significant lung atelectasis

Incidence of significant lung atelectasis being defined as an aeration score ≥2 in any lung zone (Figure 3).

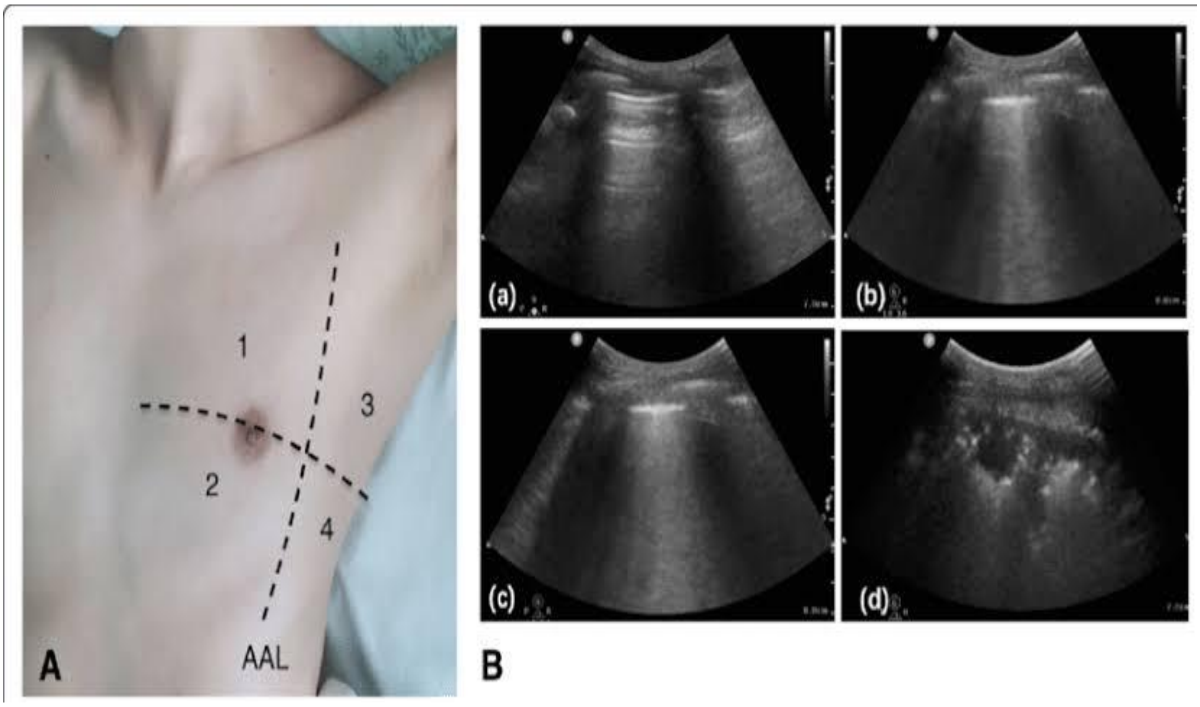

Figure 1: (A) Anterior axillary line and line one cm above the nipple showing anterior and axillary zones. Posterior axillary line delineates the posterior lung regions; (B): Four LUS patterns according to the degree of B lines: (a) fewer than three isolated B lines; (b) multiple well defined B lines; (c) multiple coalescent B lines; (d) white lung/complete loss of aeration [11].

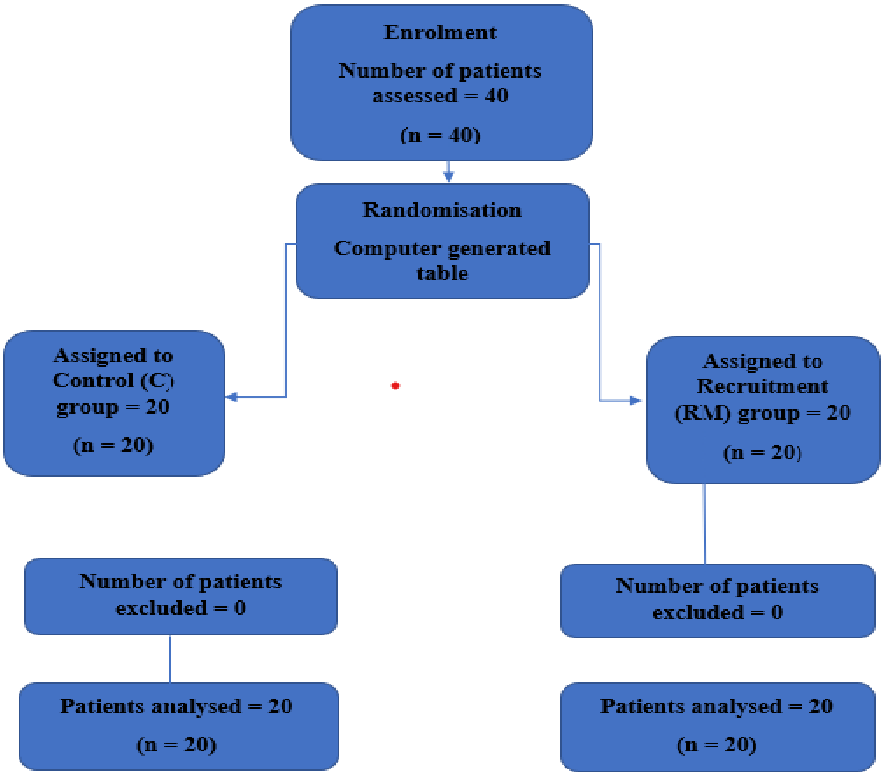

Figure 2: Flowchart showing the process of enrolment, randomization, and exclusion of patients in our study.

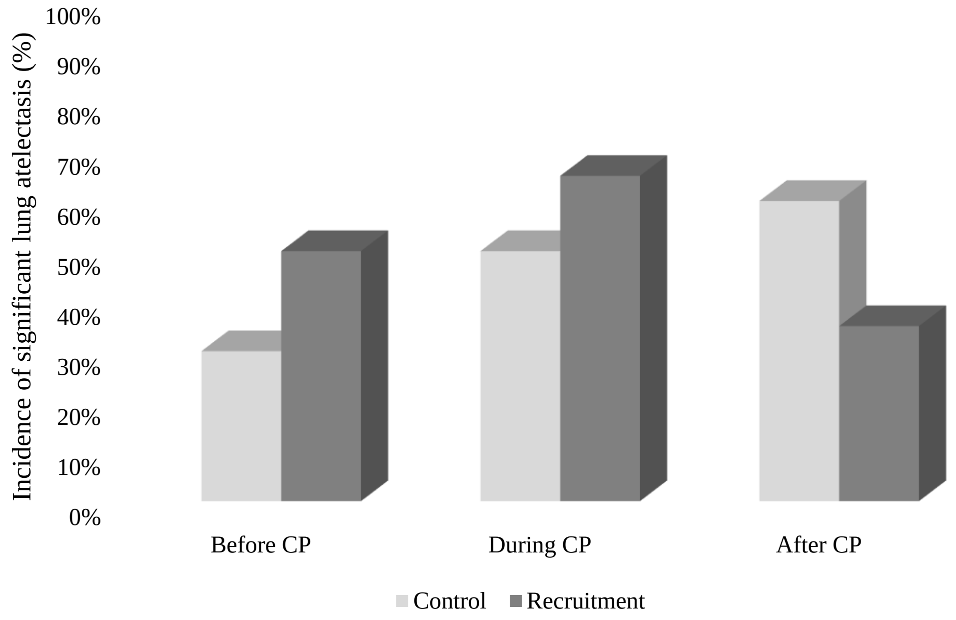

Figure 3: Percentage of occurrence of lung atelectasis before, during and after capnoperitoneum (CP) between the 2 groups (Control and recruitment group).

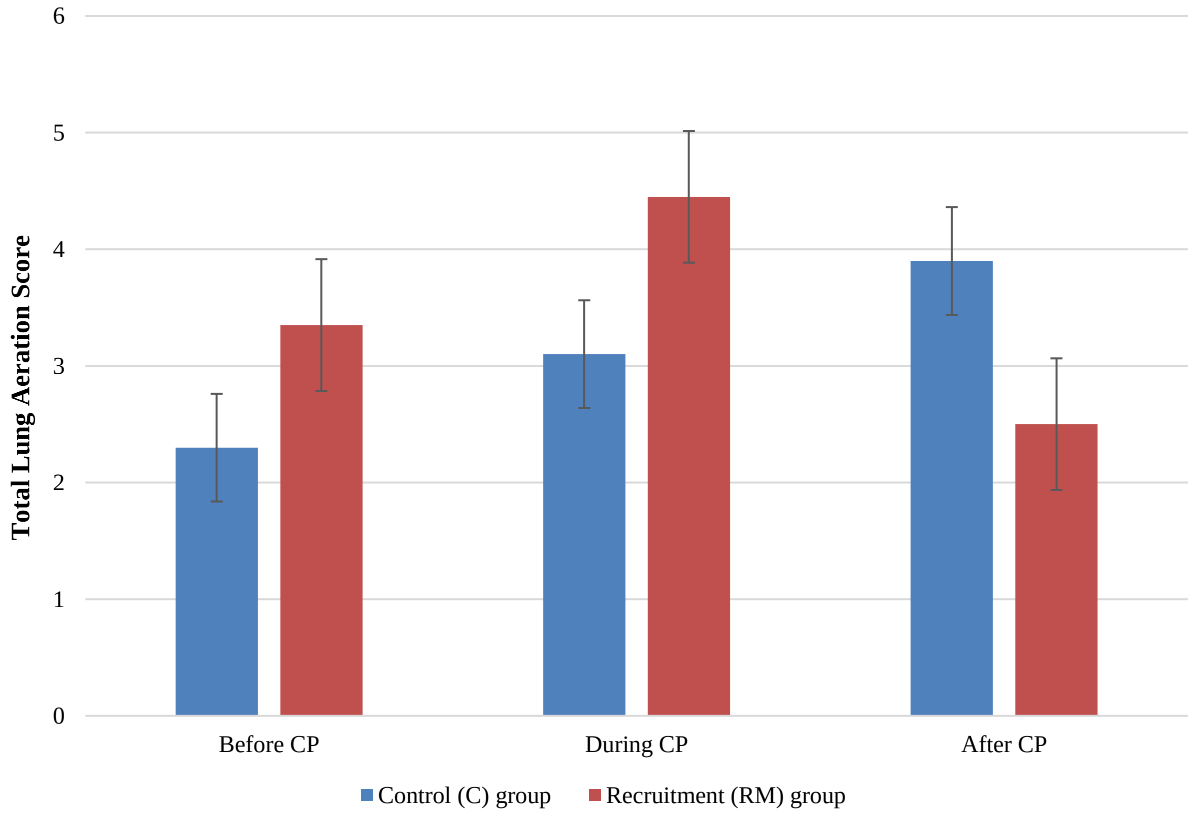

Figure 4: Figure showing the Total Lung Aeration score in 12 lung zones between the two groups before, during and after capnoperitoneum (CP).

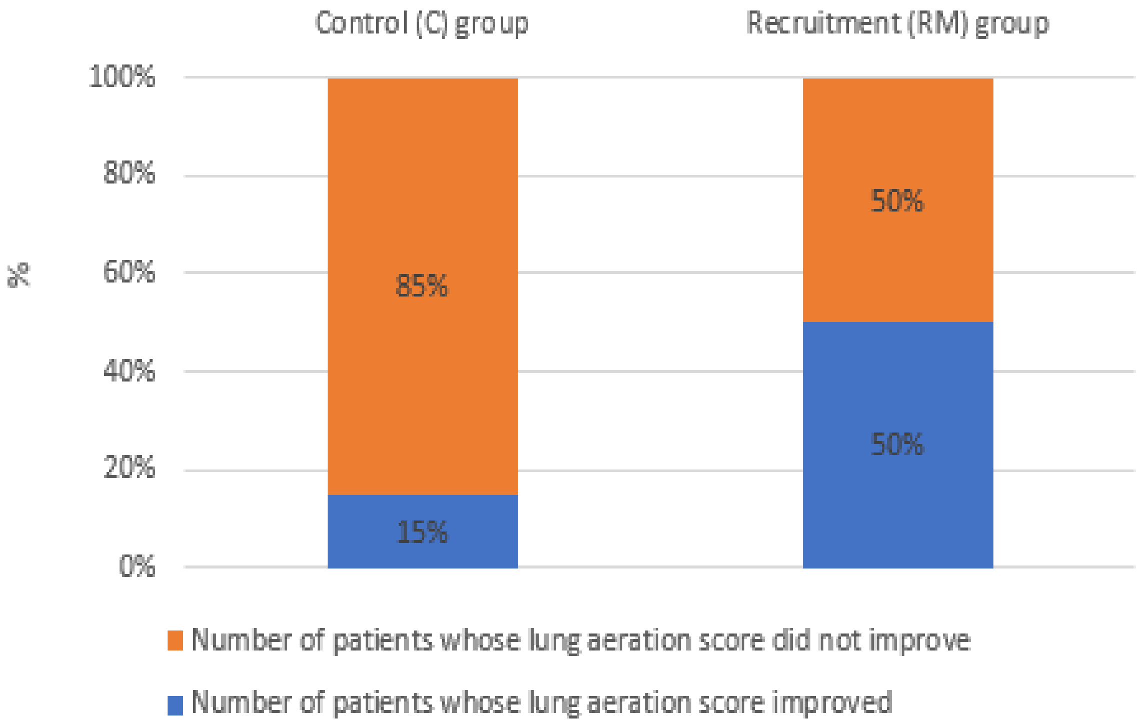

Figure 5: Bar Chart showing the percentage of patients in each group that showed an improvement in the total lung aeration score after capnoperitoneum.

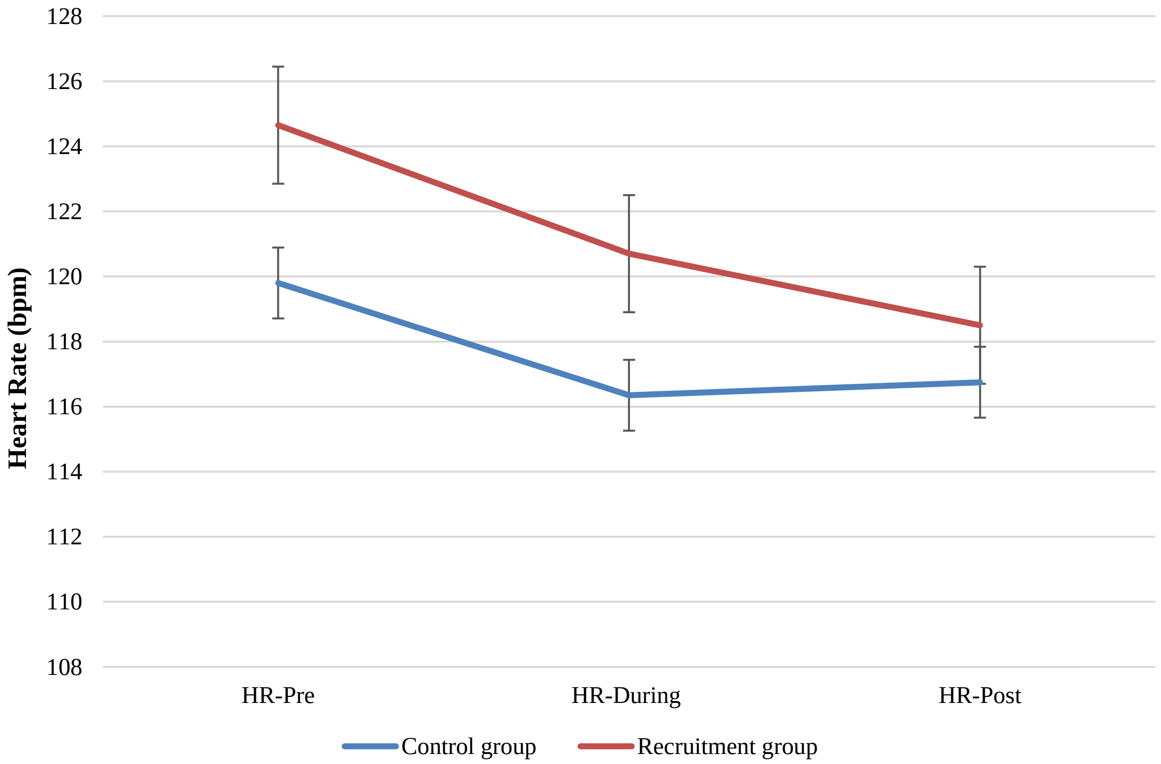

Figure 6: Figure showing the heart rate (HR) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

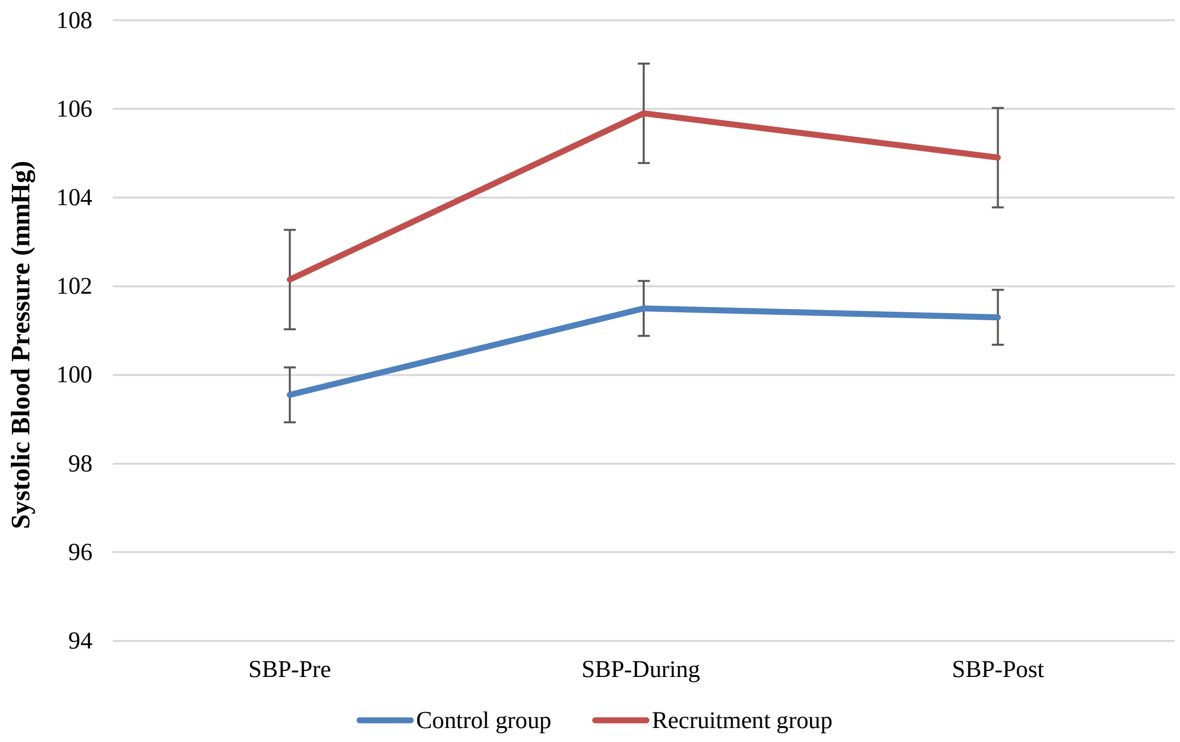

Figure 7: Figure showing the systolic blood pressure (SBP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

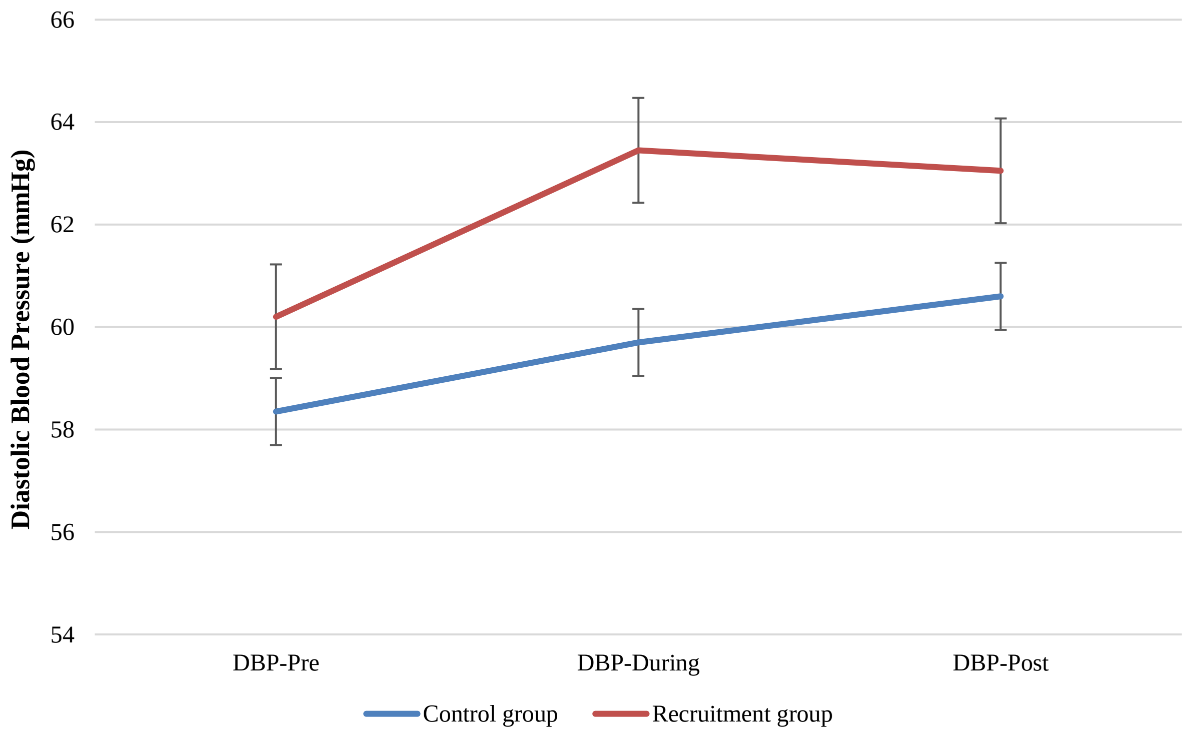

Figure 8: Figure showing the diastolic blood pressure (DBP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

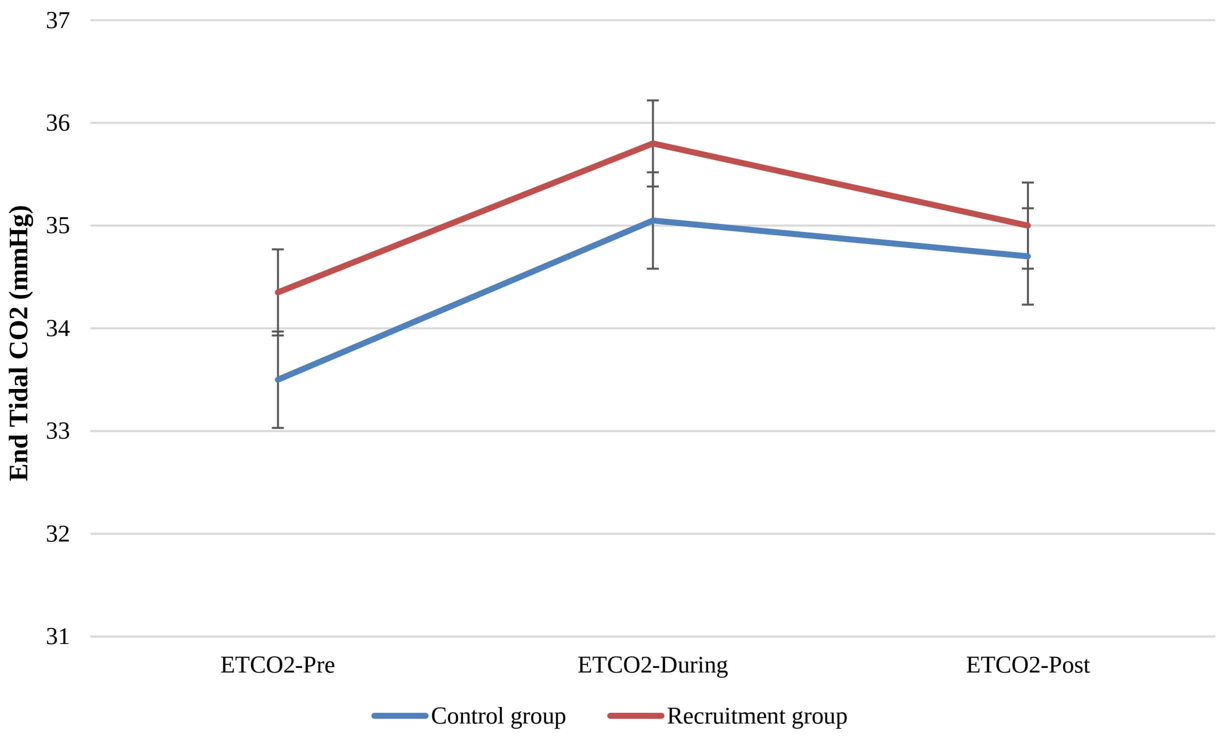

Figure 9: Figure showing the end tidal CO2 (ETCO2) as mean±SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

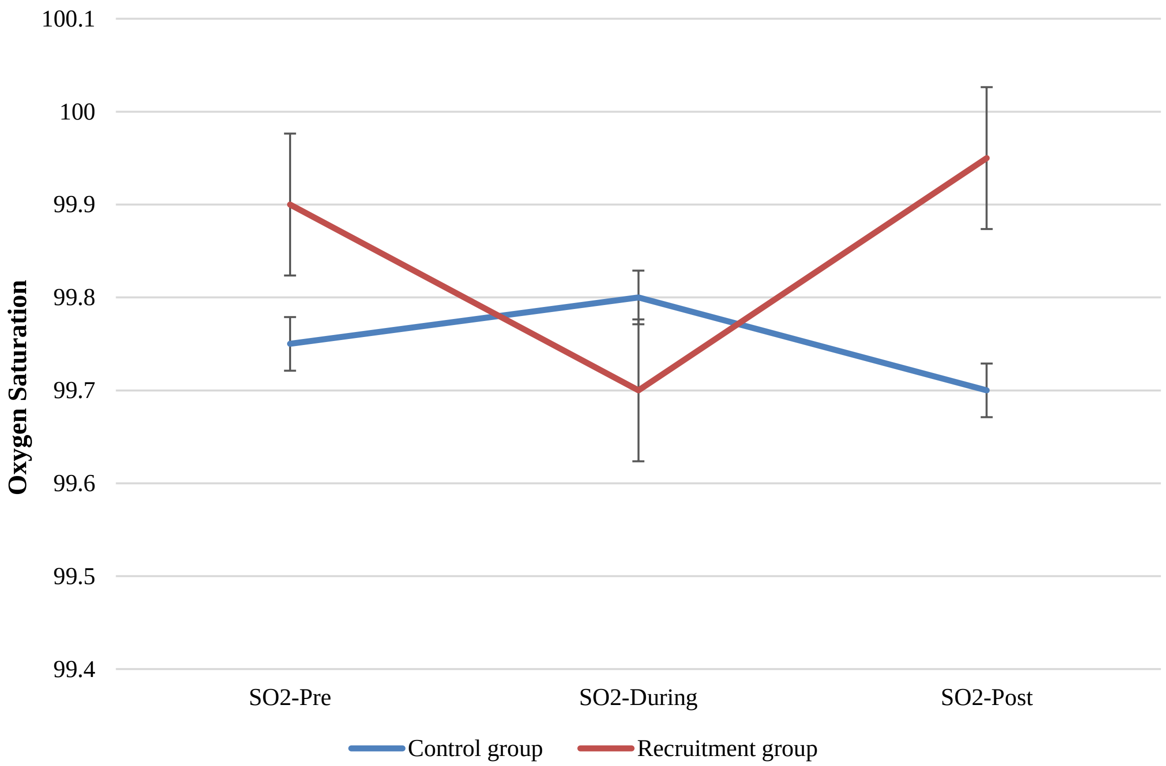

Figure 10: Figure showing the oxygen saturation (SaO2) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

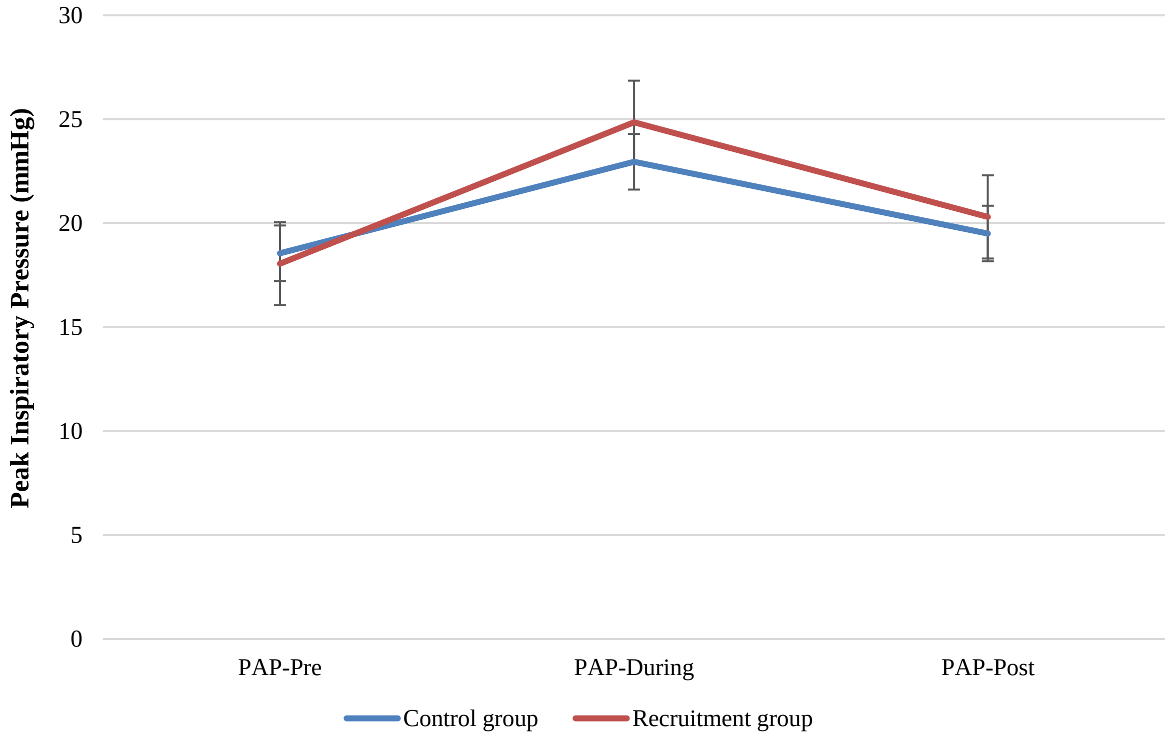

Figure 11: Figure showing the peak airway pressure (PAP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

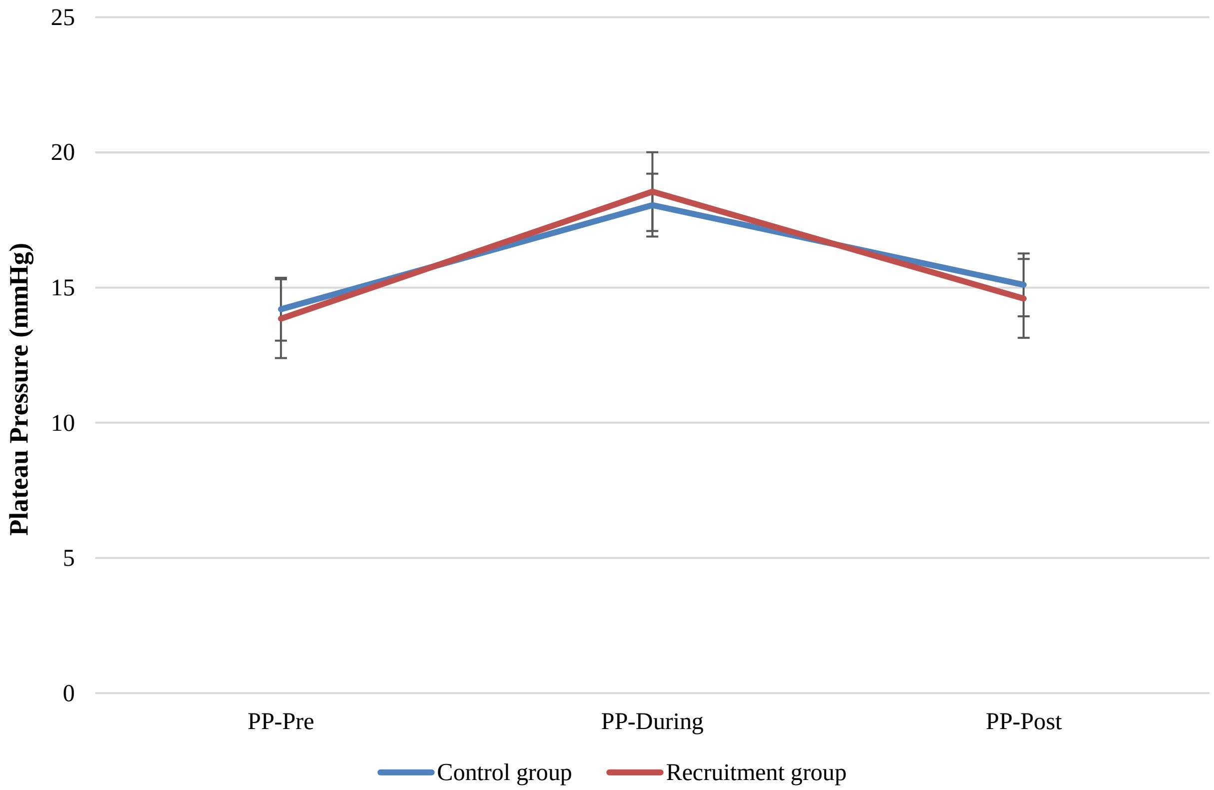

Figure 12: Figure showing the plateau pressure (PP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

Table 1: Table showing the personal characteristics and the duration of capnoperitoneum in both groups. Data represented as n % for proportions and as mean ± SD for continuous variables.

		Control (C) group (n = 20)	Recruitment (RM) group (n = 20)	*p* value
Age (years)		4.0 ± 1.6	4.2 ± 1.7	0.61
Sex	Male	15 (75)	11 (55)	0.32
	Female	5 (25)	9 (45)	
Weight (Kilograms)		16.9 ± 3.7	18.0 ± 3.9	0.65
Duration (min)		49.5±19.1	59.8±18.7	0.11

Table 2: Table showing the surgeries performed in each group. P values of 0.05 or lower are considered statistically significant.

	Control (C) group (n = 20)	Recruitment (RM) group (n = 20)	*p* value
Laparoscopic undescended testis repair	6	4	0.6
Laparoscopic Appendectomy	5	5	
Laparoscopic Cholecystectomy	2	3	
Laparoscopic ovarian cyst removal	3	4	
Laparoscopic gonadectomy	2	2	
Diagnostic Laparoscopy- pull through	2	2	

Table 3: Data presented as p values between the different time points (inter-group) and between both groups. P values of 0.05 or lower are considered statistically significant.

Protocol	Control (C) group *p* value	Recruitment (RM) group *p* value	*p* value
Before capnoperitoneum			0.19
During capnoperitoneum	0.219	0.250	0.34
After capnoperitoneum	0.146	0.146	0.11

Table 4: Table showing the mean ± SD for the total lung aeration score at the specified time points for both groups. Two-sided *p* values less than 0.05 was considered statistically significant. No statistical significance was found between the two groups.

	Control (C) group (n = 20)	Recruitment (RM) group (n = 20)	*p* value
Before capnoperitoneum	2.3 ± 1.9	3.4 ± 2.5	0.15
During capnoperitoneum	3.1 ± 2.1	4.5 ± 2.4	0.06
After capnoperitoneum	3.9 ± 2.5	2.5 ± 2.3	0.07

Table 5: The difference between the total lung aeration score before and after capnoperitoneum in both groups was calculated. (Delta score). Data presented as n (%) for the number of patients whose total lung aeration score improved after capnoperitoneum. P values of 0.05 or lower are considered statistically significant.

	Control (C) group (n = 20)	Recruitment (RM) group (n = 20)	*p* value
Delta score (difference between the total lung aeration score before and after capnoperitoneum)	1.6 ± 2.2	-0.9 ± 1.7	<0.001
Number of patients whose lung aeration score improved	3/20 (15%)	10/20 (50%)	0.04

Table 6: Table showing a pearson correlation between the total lung aeration score after capnoperitoneum and the duration of capnoperitoneum. No statistical significance was found in control group. However, a negative correlation (p value 0.045) was established between the total lung aeration score after capnoperitoneum and the duration of capnoperitoneum.

	Control group (n = 20)	Recruitment group (n = 20)
Pearson Correlation	-0.124	-0.453
***p* value**	0.602	0.045

Table 7: Table showing the heart rate (HR) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

	Control group (n =20)	Recruitment group (n = 20)	p value
HR-Pre	119.8 ± 13.89	124.7 ± 12.8	0.14
HR-During	116.4 ± 17.5	120.7 ± 12.9	0.37
HR-Post	116.8 ± 17.1	118.5 ± 14.9	0.87

Table 8: Table showing the systolic blood pressure (SBP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

	Control group (n =20)	Recruitment group (n = 20)	p value
SBP-Pre	99.6 ± 15.4	102.2 ± 9.6	0.32
SBP-During	101.5 ± 13.3	105.9 ± 10.9	0.36
SBP-Post	101.3 ± 13.3	104.9 ± 11.3	0.36

Table 9: Table showing the diastolic blood pressure (DBP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

	Control group (n =20)	**Recruitment group (n = 20)**	**p value**
DBP-Pre	58.4 ± 12.6	60.2 ± 7.9	0.44
DBP-During	59.7 ± 9.7	63.4 ± 8.9	0.23
DBP-Post	60.6 ± 9.4	63.1 ± 9.0	0.61

Table 10: Table showing the end tidal CO2 (ETCO2) as mean±SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

	Control group (n = 20)	**Recruitment group (n = 20)**	**p value**
ETCO2-Pre	33.5 ± 3.7	34.4 ± 3.2	0.11
ETCO2-During	35.1 ± 1.4	35.8 ± 2.7	0.27
ETCO2-Post	34.7 ± 1.6	35.0 ± 1.7	0.5

Table 11: Table showing the oxygen saturation (SaO2) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

	Control group (n = 20)	**Recruitment group (n = 20)**	**p value**
SO2-Pre	99.8 ± 0.6	99.9 ± 0.3	0.57
SO2-During	99.8 ± 0.5	99.7 ± 0.7	0.65
SO2-Post	99.7 ± 0.6	99.9 ± 0.2	0.08

Table 12: Table showing the peak airway pressure (PAP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

	Control group (n = 20)	Recruitment group (n = 20)	p value
PAP-Pre	18.6 ± 3.4	18.1 ± 3.1	0.58
PAP-During	22.9 ± 4.2	24.9 ± 4.8	0.25
PAP-Post	19.5 ± 3.9	20.3 ± 3.6	0.45

Table 13: Table showing the plateau pressure (PP) as mean ± SD (Standard deviation) at the predefined time points in both groups (Contol and recruitment group).

	Control group (n = 20)	Recruitment group (n = 20)	p value
PP-Pre	14.2 ± 4.1	13.9 ± 3.3	0.82
PP-During	18.0 ± 5.5	18.6 ± 6.3	0.96
PP-Post	15.1 ± 4.4	14.6 ± 4.9	0.55

4. Conclusions

The main finding in our study was that applying sustained inflations as a recruitment manoeuvre every 20 minutes followed by a PEEP of 8 cmH2O in paediatric patients undergoing laparoscopic surgery improved the total lung aeration score compared to the baseline scores (before capnoperitoneum) detected by lung ultrasonography. This suggests that the negative effects of anaesthesia and capnoperitoneum persisted in paediatric patients that received a standard ventilation strategy with no recruitment manoeuvre applied. The recruitment maneuver (repeated sustained inflations) was well tolerated hemodynamically and showed no cmplications. LUS has great potential as it represents a radiation-free, non-invasive and reliable tool for assessing lung aeration at the bedside.

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