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Impact of Lung Ultrasound Use on Postoperative Outcome in Fast Track Adult Cardiac Surgery: A Randomized Controlled Study

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ABSTRACT
Background: Although lung ultrasound (LUS) has been widely used in the critical care setting, its applications in perioperative management of different lung pathologies are still limited.
Objective: This randomized controlled study aimed to evaluate the benefits of perioperative LUS followed by LUS-guided recruitment maneuver in adults undergoing open heart surgery.
Methods: One hundred patients admitted for elective cardiac surgery were enrolled in this trial. They were divided into two groups; the control group (Group C) included 50 patients who underwent LUS without LUS guided interventions, and LUS group (Group L) included the remaining patients who underwent LUS followed by LUS-guided recruitment maneuver and other interventions according to the finding.
Results: Baseline characteristics of the study population and perioperative variables showed no significant difference between the study groups. Postoperative pulmonary complications tended to be significantly higher in Group C (22% versus 6% in Group L – p = 0.021). the incidence of postoperative desaturation was significantly higher in the control group than in the intervention group. However, the incidence of intraoperative desaturation was similar between the control and intervention groups. Better aeration, B-line, and compliance scores were detected when LUS-guided recruitment was applied. Additionally, Group L expressed higher O_2 saturation in most of the recorded readings. There was a significant decline in the duration of postoperative mechanical ventilation and the need for respiratory support LUS-guided recruitment was applied.
Conclusions: Postoperative pulmonary outcomes showed a significant improvement in association with LUS-guided recruitment maneuvers and other interventions after adult cardiac surgery.
Keywords: Lung ultrasound; Recruitment; Open heart surgery.

INTRODUCTION
Postoperative pulmonary complications are frequently encountered following cardiac surgical procedures. It leads to a significant rise in morbidity and mortality after such procedures. It increases the length of hospitalization, delays patient recovery, and increases associated healthcare costs [1]. Additionally, about 5 – 8% of mortality after these procedures are caused by these negative pulmonary consequences [2]. Multiple risk factors are incriminated in the development of such complications, which include preoperative, intraoperative, and postoperative factors. Preoperative factors include older age, patient frailty, smoking, and the presence of underlying chest disease, whereas intraoperative factors include fluid management, physical lung manipulation, and cardiopulmonary bypass (CPB)-associated inflammation. Moreover, postoperative factors include pain management protocols, immobilization, diaphragmatic dysfunction, and weaning strategy [3-5]. Among these pulmonary complications, atelectasis is the most common one, as its incidence ranges between 54% and 92% following cardiac surgery. It is the main etiology of deterioration of patient oxygenation and pulmonary functions after these procedures [6, 7].

The application of lung ultrasound (LUS) has become popular in critical care settings after the standardization of its techniques and recommended applications [8, 9]. Its value has been established in the diagnosis and monitoring of patients during the perioperative period. It has many advantages, including non-exposure to radiation, availability in most centers, non-invasiveness, low cost, and providing a real-time image for the examined region [10-12].

LUS could provide bedside detection of multiple pulmonary pathologies like consolidation, pleural effusion, interstitial pulmonary edema, and pneumothorax [13-15]. Despite the previous pros of LUS, its application in the perioperative cardiac setting is still limited to a few conditions like pleural effusion and diaphragmatic excursion [16, 17]. The value of this radiological modality in lung recruitment maneuvers, along with other interventions, is poorly studied in the current literature, especially in adults [18]. In this study, we evaluated the benefits of perioperative LUS followed by LUS-guided recruitment maneuver in adults undergoing open heart surgery.

PATIENTS AND METHODS
This randomized controlled study was conducted at Mansoura University Hospitals during the period from January 2020 till August 2021. The study included adult patients aged more than 18 years scheduled for elective open heart surgery, including valve replacement or coronary artery bypass graft (CABG) with CPB.

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Exclusion criteria: we excluded patients with previous thoracic surgery, obesity BMI ≥ 35 kg/m^2, underlying pulmonary disease, preoperative O_2 saturation 95% or less in room air, chest wall deformities, neuromuscular disorders, chronic kidney disease, and who required emergent cardiac operations.

Using computer-generated randomization software (http://www.randomization.com), 102 eligible patients were randomly assigned to one of two groups: a control or an intervention, with a 1:1 allocation ratio. After inducing general anaesthesia, consecutively numbered, opaque, sealed envelopes containing group assignments were unsealed. The group allocation and instructions for the attending anesthesiologist are included in each envelope. Control group (Group C) included 51 patients who were subjected to LUS without LUS guided interventions, and the LUS group (Group L) included the remaining patients who underwent LUS followed by LUS guided recruitment maneuver and other LUS guided interventions according to the LUS findings was done 1 min after intubation & initiation of mechanical ventilation, at the end of surgery and 4 h postoperative in ICU.

Both groups were subjected to the standard preoperative assessment, including history, clinical examination, and required laboratory and radiological investigations. All patients were kept fasting six hours prior to the operation. Preoperative LUS was done only in Group L.

In the operative room, the standard hemodynamic monitoring, including pulse oximetry, noninvasive and invasive blood pressure measurement, electrocardiography, and central venous pressure, were done. Baseline activated clotting time (ACT) was also ordered. After preoxygenation with 100% O_2, anesthesia was induced by propofol (2 mg/kg), atracurium (0.5 mg/kg), midazolam (0.1 mg/kg), and fentanyl (5 mcg/kg). After insertion of a suitable endotracheal tube, anesthesia was maintained by air–oxygen mixture with isoflurane and atracurium (0.1 mg/kg) every 20 min. Mechanical ventilation was started with a volume-controlled mode (VCV) to achieve 8 ml/kg tidal volume, a 5 cmH_2O positive end-expiratory pressure (PEEP), a 0.4 fractional inspired O_2 tension (FIO_2), and an adjusted respiratory rate to keep end-tidal CO_2 between 35 and 40 mmHg, with 1: 2 inspiratory to expiratory ratio.

After surgery started, the lungs were temporarily deflated to decrease the risk of its injury during sternotomy. Heparin was commenced at a 400 IU/kg dose to achieve an ACT between 400 and 480 seconds. Then, cardiac cannulation was performed. CPB was primed using 1300 ml of mannitol (0.5 gm/kg) and ringer acetate. The lungs were completely deflated and not ventilated when they were on the CPB, and they were kept anesthetized by fentanyl (1 mic/kg/hour), propofol (3 mg/kg/hour), and atracurium (5 – 10 mic/kg/minute). The temperature was kept between 30 and 35°C, at a flow rate of 2.5 l/minute/m^2 or more to keep the perfusion pressure between 50 and 80 mmHg and a hematocrit value of 22 or more. On weaning from the CBP, mechanical ventilation of the lungs was done using the same previous settings after suctioning of the accumulated secretions. Protamine sulphate was commenced at a dose of 1 – 1,5 mg for each 100 IU heparin to achieve the baseline ACT (total protamine dose not exceeding 50 mg).

After surgery, the patient was transferred to the intensive care unit (ICU) on Ambu bag ventilation. Then, the patient was mechanically ventilated with the same previous intraoperative parameters, apart from the mode that was changed to a pressure-regulated volume-controlled (PRVC) mode mode to deliver a tidal volume of 8 ml/kg, a positive end-expiratory pressure (PEEP) of 7 cmH_2O, a FIO_2 of 0.4, and rate adjusted to maintain end-tidal carbon dioxide (ETCO2) of 35 to 40 mmHg, with an inspiratory:expiratory ratio of 1:2. Patient sedation was achieved via fentanyl (0.5 mcg/kg/hour). A chest x-ray was ordered for both groups on arrival to the ICU, just before extubation, and then 24 hours after ICU admission.

The criteria for extubation were $PaO_2/FIO_2 \geq 200$ mmHg from ABG (PaO_2 80 mmHg on Fio_2 0.4) with an adequate level of consciousness (GCS > 13), spontaneous respiration, good metabolic status from ABG and hemodynamic stability or on minimal vasopressors without bleeding. While the criteria for ICU discharge were stable hemodynamics and rhythm without inotropic support, adequate ventilation and oxygenation without mechanical ventilatory support, and adequate diuresis and mentation. The case was excluded if there was intra or postoperative surgical complication.

The diagnosis of PPC was confirmed when ≥4 of the following criteria were present according to the Melbourne group scale version 2 (MGS-2) [(19)]: Chest radiograph report consolidation / collapse, raised temperature more than 38 C for ≥2 consecutive days, Spo2 less than 90% on two consecutive days, production of yellow or green sputum which is differ from preoperative assessment, an otherwise unexplained white cell count more than 11 109 * L-1 or prescription of antibiotic specific for respiratory infection, physicians diagnosis of chest infection, presence of infection on sputum culture report and abnormal breath sounds on auscultation which differ from preoperative assessment.

Technique of lung ultrasound (LUS) and LUS-guided lung recruitment:

LUS (in both groups) followed by LUS guided recruitment maneuver and other LUS guided interventions (in group L) according to the LUS findings was done. LUS was performed via Vivid T8 R2.5 (GE Healthcare, USA) by three anesthesiologists (all at least performed the technique 50 times) when the patient was in the supine position, following the steps previously described by **Acosta and his colleagues** [20]. Each hemithorax was divided into six zones by two horizontal lines (one above the diaphragm and the other above the nipple) and three vertical ones (parasternal, anterior, and posterior axillary lines). The created 12 regions were scanned from right to left, in a cranial-to-caudal direction, anteriorly then posteriorly.

The LUS examination was initiated using the superficial probe for the assessment of pleura and lung sliding, while the deep probe was used for the rest of the examination. In obese individuals, the latter was used from the start. The probe was positioned longitudinally oriented to the patient's head to see the pleural line between two ribs. Lung consolidation was graded using a four-point scale ranging between 0 and 3 (0 for no consolidation, 1, 2, and 3 for minimal, small, and large-sized consolidations, respectively), as described by **Song *et al*.** [18]. B-lines were graded as follows; 0 for < 3 isolated lines, 1 for multiple well-defined lines, 2 for multiple coalescent lines, and 3 for white lung [21]. Pleural effusion (PE) was also graded according to the previous four-point scale published by **Prina *et al.*** [22], with 0 for no effusion, while 1, 2, and 3 were used for minimal, small, and moderate effusion amounts, respectively.

The recruitment maneuver was done in Group L after each LUS assessment when significant atelectasis (consolidation score ≥ 2 at any region) was detected. Using LUS-guided visualization, we increased airway pressure at a 5-cmH_2O stepwise, with FIO_2 of 0.4, till no consolidation areas were detected. Each pressure increase was kept for five seconds till reaching a maximum pressure of 40 cmH_2O. The same previous mechanical ventilation settings were applied after finishing that recruitment. Recruitment maneuver was discontinued at any time if hemodynamic instability occurs at any time (20% decrease in invasive blood pressure and heart rate than basal before initiation of the maneuver).

Study Outcomes:

The primary outcome was the incidence of postoperative pulmonary complications, whereas secondary outcomes included the incidence of desaturation, LUS scores, the duration of postoperative mechanical ventilation, and the need for continuous positive airway pressure (CPAP) after mechanical ventilation, the length of ICU stay, PaO2/FIO2 (P/F) ratio and compliance.

Ethical considerations:

The study was initiated after gaining approval from the "Institutional Review Board" (IRB) of Mansoura University Hospitals (IRB code: MD. 19.07.200). Before enrollment, all patients signed an informed consent explaining the benefits, advantages, and disadvantages of each approach. The study has been executed according to The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical Analysis

The previous parameters were collected and analyzed via the SPSS software. Categorical data were expressed as numbers and percentages, then compared between the two groups using the Chi-Square, Fischer Exact, or Monte Carlo tests based on the number of categories. Quantitative variables were expressed as mean (with standard deviation) or median (with range) according to data normality. For the former, the Student-t-test was used to compare the two groups, whereas the paired-t-test was used to compare time periods within the same group. For the latter, the Mann-Whitney test was applied when comparing the two groups, while the Wilcoxon signed rank test was applied when comparing different time points within the same group. For all tests performed, a p-value ≤ 0.05 was considered significant.

Sample Size Calculation:

Our sample size was estimated by the G*POWER software considering the incidence of postoperative pulmonary complications detected in the previous study of **Cueva *et al.*** [23] as our primary objective. The incidence of these complications in the previous study was 53% and expected to decrease down to 30%. Ninety-two patients were required to achieve a 90% power, and that number was increased up to 106 for the expected 15% dropouts.

RESULTS

From January 2020, to August 2021, 106 patients were enrolled and randomized into the control (n = 51) and intervention (n = 51) groups, respectively. Two patients were excluded from the final analysis because of postoperative surgical complications.

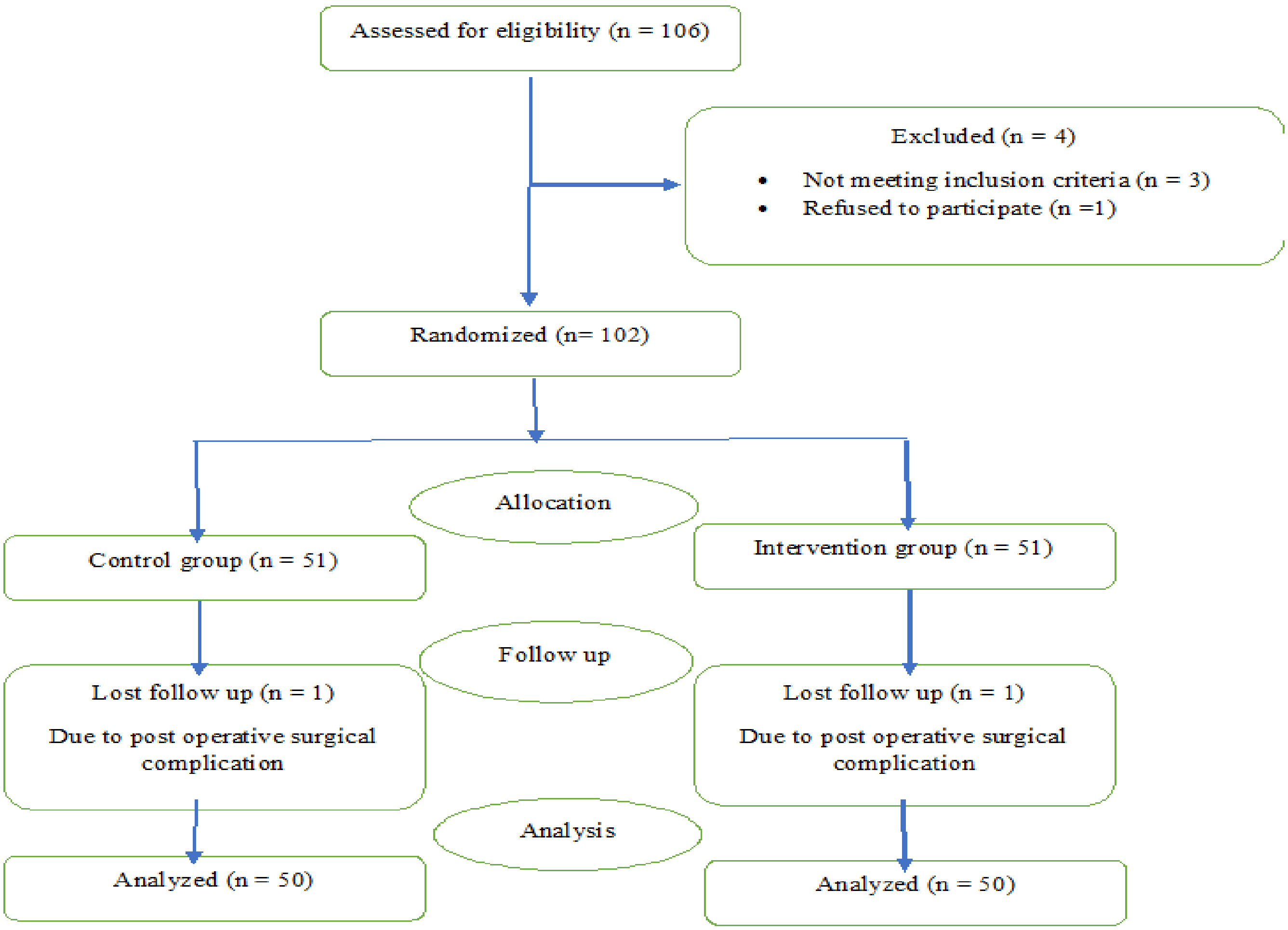

Figure (1): CONSORT Flow diagram.

Baseline characteristics of the study population and perioperative variables are summarized in tables (1 & 2) that showed non-significant difference between the two study groups. The two study groups expressed statistically comparable preoperative parameters, including age, gender, and body mass index (BMI).

Regarding the operations performed, valve replacement was done in 44% and 36% of cases, while CABG was done in 40% and 58% of cases in Groups C and L, respectively. In addition, the combination of the previous two procedures were performed in 6% and 4% of patients in the same two groups, respectively.

The remaining patients had other procedures in both study groups. Preoperative ejection fraction (EF) had mean values of 58.86% and 58.68%, whereas pulmonary blood pressure had mean values of 38.44 and 37.3 mmHg in the same study groups, respectively.

No significant difference was noted between the two study groups regarding the previously mentioned parameters (Table 1).

Table (1): Demographic and preoperative data

	Group C (n = 50)	**Group L (n = 50)**	**Test of significance**
Age (years)	49.66 ± 11.60	52.86 ± 11.40	t = -1.391 P= 0.167
Gender (%)			
Male	33 (66%)	36 (72%)	χ2= 0.421 P= 0.517
Female	17 (34%)	14 (28%)	
BMI (kg/m2)	30.28 ± 2.63	30.56 ± 2.36	t= - 0.561 P= 0.576
Surgery (%)			
Valve replacement	22 (44%)	18 (36%)	MC = 4.920 P= 0.178
CABG	20 (40%)	29 (58%)	
Combination	3 (6%)	2 (4%)	
Other	5 (10%)	1 (2%)	
Preoperative EF (%)	58.86 12.26	58.68 ± 13	t = 0.071 P= 0.943
Preoperative pulmonary blood pressure (mmHg)	38.44 ± 5.36	37.30 ± 5.57	t = 1.043 P= 0.300

t: Independent samples t-test, χ2: Chi-Square test, MC: Monte0-Carlo test

Operative data showed no significant difference between the two study groups (p > 0.05). CBP time had mean values of 119 and 121.6 minutes, while the same values were 244.6 and 248.4 minutes for the duration of anesthesia in Groups C and L, respectively. Intraoperative fluid balance ranged between ± 500 ml in both study groups (Table 2).

Table (2): Operative data.

	Group C (n = 50)	Group L (n = 50)	Test of significance
CBP time (min)	119 ± 28.10	121.60 ± 21.22	t= -0.522 P= 0.603
Duration of anesthesia (min)	244.60 ± 67.92	248.40 ± 39.14	t= -0.343 P= 0.733
Intraoperative fluid balance (ml)	0 (-500:500)	0 (-500:500)	z= -0.201 P= 0.841

Z: Mann-Whitney U-test, t: Independent samples t-test

As a primary outcome, postoperative pulmonary complications were more encountered in Group C (6% versus 22% in Group L – p = 0.021) (Table 3).

Table (3): Incidence of postoperative pulmonary complications

	Group C (n = 50)	Group L (n = 50)	Test of significance
Incidence of postoperative pulmonary complications (%)	11 (22%)	3 (6%)	FET = 5.316 P= 0.021*

t: Independent samples t-test FET: Fischer's exact test
*: Statistically significant (p< 0.05)

Although the incidence of desaturation was comparable between the two groups showing significantly higher in the control group than in the intervention group in postoperative period (64% *vs*. 36%; *P* < 0.001). However, the incidences of intraoperative desaturation (40% *vs.* 30%; *P* = 0.295) and during transfer to the intensive care unit (14% *vs.* 4%; *P* = 0.081) were similar between the control and intervention groups (Table 4).

Table (4): Incidence of desaturation

	Group C (n = 50)	Group L (n = 50)	Test of significance
Intraoperative desaturation (%)	20 (40%)	15 (30%)	$\chi 2$= 1.099 P= 0.295
Desaturation during transportation (%)	7 (14%)	2 (4%)	FET = 3.053 P = 0.081
Postoperative Desaturation (%)	32 (64%)	18 (36%)	$\chi 2$= 7.840 P < 0.001*

Z: Mann-Whitney U-test, *: Statistically significant (p< 0.05)

In the intervention group, 39 (78%) patients on the preoperative lung ultrasound examination, 21 (42%) patients on the postoperative lung ultrasound examination, and 26 (52%) patients on the intensive care unit lung ultrasound examination received a lung ultrasound-guided recruitment maneuver (Table 5). Recruitment maneuver was terminated in 2 cases one in post-operative and the other in intensive care unit due to haemodynamic instability. No other complications such as arrhythmia, or lung injury were associated with the recruitment maneuver.

As regard LUS scores, one minute after intubation, group L patients had median values of 15, 16, and 0 for the aeration, B-line, and PE scores, respectively.

At the end of the surgery, all of the previous scores showed a significant decline in group L compared to group C (p < 0.05). Apart from the PE score, which was statistically comparable between the two groups (p = 0.865). When comparing group L parameters to its baseline values before surgery, both aeration and B-line scores showed a significant decline (p < 0.001). The previous two parameters had median values of 9 and 10, respectively.

Four hours after surgery, the aeration score had median values of 20 and 13, while the B-line score had median values of 19 and 14 in groups C and L, respectively, with a significant decline in group L (p < 0.001). Contrarily, the PE score did not express significant differences between the two groups. On intragroup analysis, both aeration and B-line scores showed a significant increase when compared to the values measured at the end of the operation (Table 5).

Table (5): Lung ultrasound scores and need for recruitment in group L.

	Group C (n = 50)	Group L (n = 50)	Test of significance
One minute after intubation			
Aeration score		15 (2-26)	
Recruitment (%)		39 (78%)	
B-line score		16 (2-25)	
PE score		0 (0-6)	
At the end of surgery			
Aeration score	13 (1 – 22)	9 (2 – 18)	z = - 2.853 P= 0.010*
Recruitment (%)		21 (42%)	
		< 0.001*	
B-line score	17 (4 – 31)	10 (0 – 20)	z= -4.127 P < 0.001*
		< 0.001*	
PE score	0 (0 – 10)	0 (0 – 6)	z= -0.170 P= 0.865
		0.564	
At 4 hours postoperative			
Aeration score	20 (5 – 31)	13 (2 – 24)	z = - 4.216 P < 0.001*
	< 0.001*	< 0.001*	
Recruitment (%)		26 (52%)	
B-line score	19 (8 – 33)	14 (2 – 25)	z= -3.506 P < 0.001*
	< 0.001*	< 0.001*	
PE score	0 (0 – 10)	0 (0 – 7)	z= -0.474 P = 0.635
	0.642	0.692	

Z: Mann-Whitney U-test *: Statistically significant (p< 0.05)
P1: Significance in relation to basal value in each group

Post-operative fever was encountered in 26% and 8%, while post-extubation CPAP was needed in 16% and 2% of patients in groups C and L, respectively. Both of the previous parameters showed a significant decrease in group L (p = 0.021 and 0.014, respectively). The duration of postoperative mechanical ventilation had mean values of 354.6 and 283.8 minutes, while the duration of ICU stay had mean values of 32.94 and 32.08 hours in the same two groups, respectively, with a significant decline of the former in group L (p < 0.001) (Table 6).

Table (6): Post-operative data

	Group C (n = 50)	Group L (n = 50)	Test of significance
Postoperative fever (%)	13 (26%)	4 (8%)	FET = 5.741 P= 0.017*
Duration of Postoperative mechanical ventilation (min)	354.60 ± 47.99	283.80 ± 47.80	t= 7.391 P < 0.001*
Need for postextubation CPAP (%)	8 (16%)	1 (2%)	FET= 5.983 P= 0.014*
Duration of ICU stay (hours)	32.94 ± 2.35	32.08 ± 2.22	t= 1.880 P = 0.063

t: Independent samples t-test FET: Fischer's exact test *: Statistically significant (p< 0.05)

All of the measured PF values showed a significant increase in group L compared to group C (p < 0.001), at induction, after weaning, and after surgery. On intragroup analysis, all of the measured values showed a significant decline compared to their own baseline values in both two groups (Table 7).

Table (7): PF ratio of the two study groups along the duration of follow-up

	Group C (n = 50)	Group L (n = 50)	Test of significance
At induction (mmHg)	441.76 ± 104.34	514.36 ± 61.32	t= - 4.242 P < 0.001*
P1	0.016*	0.563	
After weaning (mmHg)	428.10 ± 112.56	510.14 ± 87.84	t= - 4.063 P < 0.001*
P1	< 0.001*	< 0.001*	
After sternal closure (mmHg)	433.70 ± 105.78	541.04 ± 62.25	t= - 6.184 P < 0.001*
P1	< 0.001*	< 0.001*	
Immediately postoperative (mmHg)	371.60 ± 103.84	474.66 ± 62.45	t= - 6.014 P < 0.001*
	< 0.001*	< 0.001*	
3 hours postoperative (mmHg)	319.88 ± 102.40	392.60 ± 61.43	t= - 4.306 P < 0.001*
P1	< 0.001*	< 0.001*	
6 hours postoperative (mmHg)	281.30 ± 103.91	371.04 ± 61.34	t= - 5.259 P < 0.001*
P1	< 0.001*	< 0.001*	

t: Independent samples t-test *: Statistically significant (p< 0.05), P1: Significance in relation to basal value in each group

Regarding oxygen saturation, preoperative values had mean values of 98.04 and 98.22% in groups C and L, respectively, which was statistically comparable between the study groups (p = 0.197). Although the next readings showed a significant decline in O_2 saturation when compared to the baseline values in each group. Group L expressed higher saturation compared to the other one (Table 8).

Table (8): Oxygen saturation of the two study groups along the duration of follow-up

	Group C (n = 50)	**Group L (n = 50)**	**Test of significance**
Preoperative (%)	98.04 ± 0.94	98.22 ± 0.91	t= - 1.300 P= 0.197
One minute after intubation (%)	96.26 ± 1.01	97.34 ± 0.94	t= - 5.548 P < 0.001*
P1	< 0.001*	0.005*	
After weaning (%)	95.73 ± 1.03	96.82 ± 0.95	t= -5.206 P < 0.001*
P1	< 0.001*	< 0.001*	
After sternal closure (%)	96.03 ± 0.93	97.78 ± 0.86	t= - 6.289 P < 0.001*
P1	< 0.001*	0.015*	
Immediate postoperative (%)	95.50 ± 0.64	97.56 ± 0.86	t= - 10.340 P < 0.001*
P1	< 0.001*	0.010*	
3 hours postoperative (%)	95.3 ± 0.70	97.42 ± 0.86	t= - 11.025 P < 0.001*
P1	< 0.001*	0.009*	
6 hours postoperative (%)	95.08 ± 0.94	97.16 ± 0.61	t= - 10.894 P < 0.001*
P1	< 0.001*	0.001*	

t: Independent samples t-test *: Statistically significant (p< 0.05) P1: Significance in relation to basal value in each group.

One-minute compliance had mean values of 49.64 and 55.94 in groups C and L, respectively, with a significant decrease in group L (p < 0.001). On the subsequent readings, compliance expressed a significant decrease compared to its own baseline values in both groups (p < 0.001).

Nonetheless, group L expressed higher values compared to group C on this subsequent assessment (Table 9).

Table (9): Compliance with the two study groups along the duration of follow-up

	Group C (n = 50)	**Group L (n = 50)**	**Test of significance**
One minute after intubation compliance (ml/cmH$_2$o)	49.64 ± 4.22	55.94 ± 6.03	t= - 6.053 P < 0.001*
At the end of surgery compliance score (ml/cmH$_2$o)	48.04 ± 4.33	54.36 ± 6.01	t= - 6.034 P < 0.001*
P1	< 0.001*	< 0.001*	
At 4 hours compliance score (ml/cmH$_2$o)	45.54 ± 6.20	53.38 ± 5.80	t= - 6.531 P < 0.001*
P1	< 0.001*	< 0.001*	

t: Independent samples t-test *: Statistically significant (p< 0.05) P1: Significance in relation to basal value in each group.

DISCUSSION

Lung ultrasound has been gaining consensus as a noninvasive, radiation-free tool for diagnosing various pulmonary diseases in adult and pediatric patients [24]. Lung recruitment maneuvers are generally recommended to decrease the disturbances of lung aeration disturbances following thoracic surgery [25]. The advantages of such maneuvers in decreasing postoperative pulmonary complications have been confirmed in numerous reports [26-28]. Nonetheless, these maneuvers have complications like hypotension [29]. Therefore, it should be applied carefully, especially under US guidance [20].

The current literature is poor, with studies handling the role of perioperative LUS followed by LUS-guided recruitment maneuvers in adult patients undergoing cardiac surgical procedures. That was a fair motive for us to conduct our study. On looking at patient criteria and operation types, one should notice no significant difference between our two groups, and that ensured our proper randomization technique. In addition, it should also nullify any bias skewing our findings in favor of one group rather than the other. Despite those comparable preoperative and operative surgical parameters, postoperative pulmonary complications significantly declined in association with US recruitment (6% vs. 22% in Group C – p = 0.021).

Pulmonary dysfunction attributed to CPB is thought to arise from the effects of acute systemic and pulmonary inflammatory response. In addition, the cessation of ventilation during CPB results in collapsed lungs leading to insufficient alveolar distention to activate the production of surfactant, which potentiates alveolar collapse and atelectasis [30]. In this context, pre-CPB collapsed lungs in the control group could have contributed to the inflammatory response and subsequent reactions, causing unfavorable results after CPB. In the same context, **Elshazly *et al.*** [31] reported that optimization of PEEP settings with the help of LUS guidance was associated with a marked decline in postoperative pulmonary complications following laparoscopic bariatric procedures [31]. Likewise, **Park and his associates** [32] reported that the application of LUS-guided recruitment maneuvers was associated with a marked decline in the incidence of atelectasis compared to the conventional recruitment group [32].

In the current study, postoperative desaturation was more encountered in group C ($p < 0.001$). The previous findings imply that preoperative LUS-guided recruitment had a significant positive impact on atelectasis, which occurs in conjugation with anesthetic induction. However, intraoperative desaturation was similar between the control and intervention groups that may be explained as the lungs were deflated while on CPB, that could have brought equilibration in the state of the lungs between the groups regardless of any benefit gained by LUS examination with recruitment maneuver, which was done after induction of anesthesia. In line with the previous findings, **Song *et al.*** [20] noted that intraoperative desaturation events had mean values of 1 and 0, while postoperative desaturation events had mean values of 2 and 0 in the control and intervention groups, respectively, with a significant decline in association with US recruitment maneuvers ($p = 0.007$ and 0.006 respectively).

In the current study, US-guided recruitment was done in 78% of patients one minute after intubation, 42% at the end of the surgery, and 52% at four hours post-operatively. This highlights the concept that the lung recruitment maneuver should be suited for every patient, as its application would result in hypotension, decreased cardiac output, and barotrauma [26, 33]. Individualized treatment should be commenced based on the extent of alveolar collapse and the degree of response to the applied recruitment maneuver [34].

Our findings showed that aeration and B-line scores showed a significant decrease in group L compared to group C immediately after the operation and four hours after it. In line with the previous findings, the same two scores showed the same findings when US recruitment maneuvers were applied. The post-operative consolidation score had median values of 13 and 8, whereas the B-line score had median values of 17 and 9 in the control and intervention groups, respectively. In the ICU, the former had median values of 22 and 15, whereas the latter had median values of 22 and 18, respectively, in the same groups respectively [20].

Moreover, another previous study noted that the first US assessment revealed comparable findings in the two groups regarding consolidation and B-line score ($p = 0.412$ and 0.571, respectively). Nonetheless, the second assessment showed a significant decrease in these scores in association with the recruitment maneuver ($p < 0.001$). The consolidation score had median values of 6 and 13.5, while the B-line score had median values of 6.5 and 15 in the recruitment and control groups, respectively [18]. The previous findings were also reported by **Park *et al.*** [32], and all of them are in the same context as our findings.

Our findings showed that lung compliance score showed a significant increase in group L. One-minute compliance score had mean values of 49.64 and 55.94 in groups C and L, respectively, while the same values were 48.04 and 54.36 at the end of surgery. This was also confirmed by **Elshazly *et al*.** [31] who reported that lung compliance had mean values of 38.45 and 28.05 ml/cmH_2O in the intervention and control groups, respectively, with a significant improvement in association with US-guided recruitment ($p < 0.001$). This denotes the positive impact of lung recruitment guided by the US on lung compliance during general anesthesia.

Our findings showed that all of the measured PF values showed a significant increase in group L compared to group C, at induction, after weaning, and after surgery. This was also noted in the study conducted by **Song and his associates** [20] who reported that all intraoperative and postoperative PF ratios were significantly increased in the intervention group compared to the control one. Furthermore, **Elshazly *et al.*** [31] noticed that the application of the same maneuver was associated with a significant increase in PF ratios measured at the end of surgery and the following extubation. The former had mean values of 360.8 and 417.9, while the latter had mean values of 355.65 and 441.55 in the control and recruitment groups, respectively.

In our study, postoperative oxygen saturation showed a significant decrease in group C compared to group L. These changes were noticeable immediately after surgery and after three and six hours. These changes are expected with the application of LUS-guided recruitment, as it improves oxygenation, corrects hypoxia, and decreases the need for high FIO_2 [26]. Another previous study reported that saturation had median values of 99% and 100% respectively in the control and intervention groups respectively. Despite that slight difference, statistical analysis revealed a significant decrease in the non-US recruitment group ($p = 0.018$) [20].

In the current study, the duration of ICU stay showed no significant difference between the two study groups. **Song *et al.*** [20] reported that ICU duration of stay had mean values of 67 and 53 hours in the control and intervention groups, respectively. Although the duration was decreased in the intervention group, that difference was statistically insignificant ($p = 0.145$) [20].

Our findings showed a significant decrease in the duration of mechanical ventilation in association with the US-guided lung recruitment (283.8 vs. 354.6 minutes in controls – $p < 0.001$). **Cylwik and Buda** [35] confirmed our findings, as the mean duration of mechanical ventilation was 0.25 and 2.96 hours in the intervention and control groups, respectively ($p = 0.049$).

Our study showed a decreased need for post-extubation CPAP in group L compared to group C (2% vs. 16% respectively – $p = 0.014$). It is reasonable to find an increased need for respiratory support in the group with more respiratory complications and worse respiratory parameters compared to the other group, and that was also evident in invasive mechanical ventilation, as well as non-invasive ones.

All in all, we recommend using LUS followed by US-guided lung recruitment maneuvers and other interventions not only in patients undergoing cardiac surgery but also in all patients undergoing operations under general anesthesia. That would help to decrease postoperative respiratory comorbidities.

Although our trial handled a unique anesthetic topic, it has some limitations, including the small sample size collected from one medical center. Therefore, more studies, including more patients from different cardiac centers, should be performed in the near future. Another limitation, the anesthesiologist who performed the LUS examination was not blinded, which might influenced the outcome measurements. Nonetheless, the designated anesthesiologist only performed the LUS examination and lung LUS-guided recruitment maneuver.

CONCLUSIONS

Based on the previous findings, postoperative pulmonary outcomes showed a significant improvement in association with LUS-guided recruitment maneuvers after cardiac surgery. This was evident in the decreased incidence of pulmonary complications, better ultrasound scores, improved O_2 saturation, decreased duration of postoperative mechanical ventilation, and reduced need for CPAP after extubation. The use of this maneuver is recommended in the perioperative cardiac setting to enhance patient outcomes.

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