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Intraoperative Use of Lung Ultrasound in Optimization of Positive End Expiratory Pressure during One Lung Ventilation in Thoracic Surgery

Mohammed A. Hegazy, M.D.[1], Ahmed Mostafa Elsaied, M.D.[2], Waleed Hasan Mohamed, M.D.[2], Rehab Elmorsey. M.D.[3], Mohamed Elgamal, M.D.[3]

[1]Department of anesthesia and intensive care, Faculty of medicine, Mansoura University, Egypt

[2]Department of cardiothoracic surgery, Faculty of medicine, Mansoura University, Egypt

[3]Department of chest medicine, Faculty of medicine, Mansoura University, Egypt

*Corresponding author: Dr. Mohammed Adel Hegazy, M.D., lecturer, Department of anesthesia and intensive care, Faculty of medicine, Mansoura University Hospitals, F1, 60, El Gomhoria Street, Qism 2, Mansoura 35516, Dakahlia, Egypt, Tel: +201002025982; E-mail: dr_mhegazy7000@yahoo.com

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Abstract

Background: Lung ultrasound (LUS) represents an easily repeatable noninvasive tool for assessing lung recruitment. This study was conducted aiming to compare the efficacy of LUS versus the Pressure Volume curve to assess PEEP-induced lung recruitment during one lung ventilation (OLV) in thoracic operations.

Patients and Methods: We included a total of 36 cases who were divided into two equal groups; optimal compliance PEEP (Copt) group and ultrasound guided PEEP (LUS) group. Our primary outcome was PaO_2/FiO_2. Secondary outcomes included ventilation parameters (recorded PEEP, Peak inspiratory pressure, Plateau pressure, driving pressure and lung compliance), and the incidence of postoperative desaturation.

Results: The mean age of the included cases was 44.83 and 46.61 years in Copt and LUS groups respectively. Neither demographic variables, smoking pattern, and respiratory mechanics were statistically different between the two study groups. The mean duration of OLV was 113.78 and 124.61 minutes in LUS and Copt groups respectively ($p = 0.0107$). PaO_2/FiO_2 did not significantly differ between the two study groups either before, during, or after OLV ($p > 0.05$). Ventilation parameters including recorded PEEP, Peak inspiratory pressure, Plateau pressure, driving pressure and lung compliance were not significantly different between the study groups.

Conclusion: LUS is an effective tool in titration of PEEP during OLV in thoracic surgery. Its intraoperative use was associated with improvement of both oxygenation and lung compliance as PEEP obtained through best lung compliance.

Keywords: Lung ultrasound; Positive end expiratory pressure; One lung ventilation; Best compliance

Introduction

Hypoxemia remains a clinical problem that could be encountered in about 7-10% of cases undergoing one-lung ventilation (OLV) during thoracic surgery [1]. This problem occurs due to collapse of the affected lung, which results in serious respiratory consequences. Therefore, it is crucial to maintain optimum oxygenation to avoid the incidence of such problem [2].

Furthermore, there is an increased risk for intrapulmonary shunting of deoxygenated blood when the patient is positioned in the lateral decubitus during OLV. However, the unventilated lung shows an increase in the pulmonary vascular resistance (PVR) due to hypoxic pulmonary vasoconstriction (HPV) [3]. So, redistribution of the blood flow to the ventilated lung occurs which prevents excessive decrease the partial oxygen pressure in arterial blood (PaO_2) [4].

In the ventilated lung, alveoli with low ventilation/perfusion (V/Q) coupling play a role in intrapulmonary shunt which is the principal cause of hypoxemia during OLV. Additionally, blood entering the upper parts of the lung is not sufficiently oxygenated, so it keeps the mixed venous composition. In the left atrium, it becomes mixed with the oxygenated blood, leading to PaO_2 reduction because of the formation of the so-called venous admixture [5].

There have been multiple reports evaluating the role of alveolar recruitment strategy (ARS) in the prevention of hypoxia during OLV. ARS is performed using high inspiratory pressure that is followed by external PEEP to keep opening of the recruited alveoli [6].

In ventilated patients with respiratory distress syndrome, the effects of PEEP on respiratory biomechanics could be understood by the static lung compliance curve. Also, it can be used to guide ventilation plan in intensive care units [7].

Lung ultrasound (LUS) is currently used to accurately assess changes in pulmonary aeration during multiple pathological states, including acute respiratory distress syndrome, pulmonary edema and community-acquired or ventilator-associated pneumonia [8,9]. In the previous studies, LUS depended on both types and numbers of B lines to monitor changes in lung aeration. Separated B lines is detected in the interstitial syndrome, while B lines coalescence indicates involvement of the alveolar spaces (fluid-filled lung) [10].

Dependent hemithorax was scanned using 6-12 MHz linear probe of ultrasound and was divided into 6 regions anterior (upper and lower), lateral (upper and lower) and posterior (upper and lower). Lung aeration score was used to assess lung recruitment (normal pattern=0, well separated B lines=1, coalescent B lines=2 and consolidation pattern=3). To calculate the total score, the points of each region are summed, and it ranges between 0 and 36 [11].

This study aims to compare the efficacy of LUS versus the Pressure Volume (PV) loop to assess PEEP-induced lung recruitment during OLV in thoracic operations.

Patients and Methods

This study is a prospective randomized one that was conducted at Mansoura university Hospitals after obtaining approval from the ethical committee of Mansoura University and obtaining an informed written consent from the included patient. Cases from either gender, aged between 18 and 60 years, and having American Society of Anesthesiologists (ASA) score of I-III, being prepared for elective thoracic surgery were included in the study.

On the contrary, cases with moderate to severe valvular heart disease, uncompensated liver disease, severe kidney disease, ejection fraction < 40%, previous thoracic surgeries, pulmonary bullae on preoperative imaging, ASA score IV or more were excluded.

Basic preparation included continuous vital monitoring (blood pressure, ECG, and SpO_2), established intravenous access, along with redial artery catheterization.

Induction of general anesthesia was performed by propofol (1.5–2mg/kg), fentanyl (2μg/kg), and rocuronium (0.6mg/kg). Trachea was intubated with appropriately sized double lumen tube (37 F for males and 36 F for females). Its position was checked with fiberoptic bronchoscope in both supine and lateral positions. Initially, both lungs were ventilated with tidal volume (Vt) 6-8 ml/kg of ideal body weight, respiratory rate (RR) 12-14 breaths per minute (BPM), with an inspiratory pause of 20%, inspiration to expiration ratio of 1:2, zero end expiratory pressure, and fractional inspired oxygen (FiO_2) was 50 %.

Maintenance of anesthesia was done using sevoflurane 1-1.5 MAC (Minimum Alveolar Concentration), fentanyl (1µg/kg/h), and rocuronium (0.1mg/kg) increment every 20 min. A blood sample was withdrawn from radial artery catheter for basal ABG analysis with two lung ventilation.

When one- lung ventilation (OLV) was started, recruitment maneuver was applied to the dependent lung using inspiratory pressure of 30mmHg for 10 seconds. Then, the included 36 patients were randomly allocated using closed envelop method into two equal groups:

- Optimal compliance PEEP (Copt) group: which included 18 cases to whom PEEP was titrated from 18 cmH_2O, decreased in 2 cmH_2O steps and hold at each step for 1 min, and the static pulmonary compliance (Cst) was record. Optimal PEEP was determined when the maximal static pulmonary compliance was determined.

- Ultrasound guided PEEP (LUS) group: which included 18 cases whose PEEP was initially titrated to 18mmHg. lung was scanned with 6-12 MHz linear ultrasound probe (GE vivid series) and ensured that lung aeration score was zero. After that, PEEP was decreased in decrement of 2mmHg. and it was sustained for 1min. best PEEP was considered the least PEEP without appearance of B lines.

In case of plateau pressure reached 30mmHg, Vt was decreased 1ml/kg increment. If SpO_2 was decreased below 92% in either group, gradual increase in FiO_2 in 10% increment was titrated.

Ringer acetate was infused a rate of 4ml/kg/h. Arterial blood was sampled at 10, 30 min, after institution of one-lung ventilation, and just before resuming two- lung ventilation.

At the end of surgery, 10mg/kg paracetamol, 0.5mg/kg ketorolac were given by iv infusion, in addition to 0.5 mg/kg iv meperidine. Reversal was performed using neostigmine (0.25mg/kg) and atropine (0.01mg/kg). Trachea was extubated after fulfilling extubation criteria.

Our primary outcome was PaO_2/FiO_2. Secondary outcomes included ventilation parameters (recorded PEEP, Peak inspiratory pressure, Plateau pressure, driving pressure and lung compliance), and the incidence of postoperative desaturation (SpO_2 less than 92%) within 4 hours.

Sample Size Calculation

Sample size was calculated using data from previous study on the effect of application of PEEP on PaO_2/FiO_2 ratio, improvement which was 108 and standard deviation was 81 assuming effect size 0.7. The α and β errors for the sample size were chosen as 0.05 and 0.95, respectively. Upon the previous data, 16 patients were required in each group. We increased the sample size to be 18 patients in each group to compensate for dropouts.

Statistical Analysis

Statistical analysis was performed using statistical package for social sciences (SPSS) software (SPSS Inc., Chicago, USA), version 18.0. Normality of data was assessed by Klomogorov-Smirnov test. Normally and non-normally distributed continuous data were assessed by t-test and Mann-Whitey U test. Moreover, categorical data were analyzed chi-square or Fisher's exact tests. The results were expressed as mean (SD), median and range or number and % of patients as appropriate. P value<0.05 was considered to be significant.

Results

The mean age of the included cases was 44.83 and 46.61 years in Copt and LUS groups respectively. Males represented 77.8 and 50% of cases in both groups respectively. Neither demographic variables, smoking pattern, and respiratory mechanics were statistically different between the two study groups (p>0.05). These data are illustrated at [Table -1].

Table 1: Patient data in the studied groups.

		Copt group (n= 18)	LUS group (n= 18)	95% CI	p
Age (years)		44.83 ± 8.939	46.61 ± 11.673	-8.82, 5.26	0.611
Gender	Male	77.8% (14)	50.0% (9)	-0.58, 0.02	0.083
	Female	22.2% (4)	50.0% (9)		
BMI		29.68 ± 3.790	29.85 ± 3.004	-2.48, 2.15	0.887
FEV1 (%)		82.43 ± 2.880	81.25 ± 3.843	-1.13, 3.48	0.307
FVC (%)		3.20 ± 0.167	3.08 ± 0.221	-0.01, 0.25	0.073
FEV1/FVC (%)		76.54 ± 3.379	78.28 ± 2.896	-3.87, 0.39	0.107
Smoking	None	5.6% (1)	0.0% (0)	-	0.394
	Exsmoker, > 6 months	22.2% (4)	11.1% (2)		
	Exsmoker, < 6 months	22.2% (4)	44.4% (8)		
	Smoker	50.0% (9)	44.4% (8)		

P value was insignificant. CI confidence interval of the mean difference between groups

The left bronchus was the commonest intubated side in both groups (83.3 and 77.8% of cases in Copt and LUS groups respectively). The mean duration of OLV was 113.78 and 124.61 minutes in the study groups respectively (p = 0.0107). Moreover, duration of anesthesia and the amount of infused intraoperative fluids did not differ significantly between the two groups (p > 0.05). [Table 2] illustrates these data.

Table 2: Operative data in the studied groups.

		Copt group (n= 18)	LUS group (n= 18)	95% CI	p
Surgery	**Lobectomy**	38.9% (7)	27.8% (5)	-	0.363
	Pneumonectomy	0.0% (0)	16.7% (3)		
	Decortication	27.8% (5)	16.7% (3)		
	Mediastinal mass excision	0.0% (0)	5.6% (1)		
	VATS	33.3% (6)	33.3% (6)		
Double lumen tube	**Left**	83.3% (15)	77.8% (14)	-0.31, 0.2	1
	Right	16.7% (3)	22.2% (4)		
Duration of OLV (minutes)		113.78 ± 14.375	124.61 ± 23.759	-24.14, 2.47	0.107
Duration of anesthesia (minutes)		185.56 ± 16.169	193.89 ± 26.209	-23.08, 6.42	0.259
Intra-operative fluids (ml)		2141.67 ± 333.982	2311.11 ± 349.603	- 401.04, 62.15	0.146

Data are expressed in % & (number) and mean ± SD. P value was insignificant. CI confidence interval of the mean difference between groups. OLV One Lung Ventilation

PaO2/FiO2 did not differ significantly between the two groups either before, during, or after OLV (p > 0.05). Table (3) illustrates these data.

Ventilation parameters including PEEP, plateau pressure, driving pressure, static compliance, and tidal volume were not significantly different between the study groups as illustrated in table (4).

3 patients in LUS group developed postoperative hypoxemia in face of 2 patients in Copt group p=1. Fortunately, all patients improved with chest physiotherapy and increased FiO_2.

Table (3): Oxygenation indices in the studied groups

PaO2/FiO2	Copt group (n= 18)	LUS group (n= 18)	95% CI	p
BLV	341.67 ± 79.879	330.44 ± 86.148	-45.05, 67.50	0.688
10 minutes after OLV	212.00 ± 67.088	206.78 ± 59.135	-37.62, 48.06	0.806
30 minutes after OLV	221.50 ± 68.750	224.89 ± 60.007	-47.10, 40.32	0.876
Just before OLV end	222.56 ± 70.933	236.33 ± 62.155	-58.95, 31.40	0.540
BLV end	295.22 ± 75.588	301.28 ± 66.966	-54.43, 42.32	0.801

Data are expressed in mean ± SD. P value was insignificant. CI confidence interval of the mean difference between groups

Table 4: Ventilation parameters in the studied groups.

		Copt group (n= 18)	LUS group (n= 18)	95% CI	p
PEEP	**TLV**	5.00 ± 0.0	5.00 ± 0.0	-	-
	10 minutes after OLV	8.83 ± 2.407	10.06 ± 3.506	-3.26, 0.81	0.231
	30 minutes after OLV	8.83 ± 2.407	10.06 ± 3.506	-3.26, 0.81	0.231
	Just before OLV end	8.83 ± 2.407	10.06 ± 3.506	-3.26, 0.81	0.231
	TLV end	5.00 ± 0.0	5.00 ± 0.0	-	-
Plateau	**TLV**	16.78 ± 2.390	16.44 ± 3.485	-1.69, 2.36	0.740
	10 minutes after OLV	21.67 ± 3.087	24.33 ± 4.446	-5.26, -0.07	0.044
	30 minutes after OLV	20.17 ± 3.312	22.11 ± 4.444	-4.60, 0.71	0.146
	Just before OLV end	19.89 ± 3.848	21.78 ± 4.558	-4.75, 0.97	0.188
	TLV end	15.94 ± 2.796	16.39 ± 3.256	-2.50, 1.61	0.663
Driving pressure	**TLV**	10.06 ± 4.425	11.72 ± 3.561	-4.39, 1.05	0.222
	10 minutes after OLV	12.33 ± 4.419	14.83 ± 3.915	-5.33, 0.33	0.081
	30 minutes after OLV	11.28 ± 4.470	12.67 ± 3.896	-4.23, 1.45	0.327
	Just before OLV end	11.28 ± 4.430	12.94 ± 4.007	-4.53, 1.19	0.245
	TLV end	10.06 ± 4.696	10.33 ± 4.472	-3.38, 2.83	0.857
Static compliance	**TLV**	76.75 ± 12.153	77.47 ± 13.819	-9.54, 8.09	0.869
	10 minutes after OLV	52.44 ± 8.699	49.94 ± 8.306	-3.26, 8.26	0.384
	30 minutes after OLV	49.22 ± 9.078	46.28 ± 8.330	-2.96, 8.85	0.318
	Just before OLV end	51.11 ± 8.710	49.06 ± 8.356	-3.73, 7.84	0.475
	TLV end	68.06 ± 9.477	66.67 ± 8.778	-4.80, 7.58	0.651
Tidal volume	**TLV**	479.17 ± 77.293	469.44 ± 62.753	-37.97, 57.41	0.681
	10 minutes after OLV	358.33 ± 48.507	372.22 ± 51.370	-47.73, 19.95	0.410
	30 minutes after OLV	369.44 ± 48.926	354.17 ± 36.632	-14.00, 44.55	0.296
	Just before OLV end	373.61 ± 51.786	372.22 ± 49.918	-33.06, 35.84	0.935
	TLV end	429.17 ± 81.912	459.72 ± 56.320	-78.17, 17.06	0.201

Data are expressed in mean ± SD. P value was insignificant. CI confidence interval of the mean difference between groups. TLV two lung ventilation. OLV one lung ventilation

Discussion

According to our results, we believe that lung ultrasound use is efficient as P-V loop in determination optimal PEEP during one lung ventilation in thoracic surgery. There was no statistical significance between both groups in oxygenation index (p>0.05). As regard ventilation parameters (applied PEEP, static compliance and driving pressure), there was no significant difference between both groups.

During the first few minutes following induction, general anesthesia causes atelectasis in the most dependent parts of the lung [12]. Atelectasis could affect about 15-20% of lung tissue related to diaphragm or about 10% of total lung mass in supine position during surgery, and it may increase up to 50% of lung volume during open heart surgery [13].

Application of PEEP during OLV has many advantages. It improves V/Q relationship in the dependent lung parts, increases functional residual capacity (FRC), and prevents the collapse of alveoli at end-expiration [14]. Nevertheless, PEEP could cause perialveolar vessels compression in some cases, leading to diversion of perfusion to the nonventilated lung. Therefore, increased shunt fraction Qs/Qt and decreased PaO_2 occur [15].

Optimal PEEP could be achieved by putting the lungs on the nearby vertical limb of P-V loop. PEEP is set above lower inflection point which represents the pressure at which recruitment of large number of alveoli occurs. Amato and his associates recommended to set PEEP 2 cm H_2O above this pressure. An upper inflection point on the P-V curve might represent overdistention, or it may also indicate the end of recruitment [16].

Performing a recruitment maneuver together with decremental PEEP titration represent one approach to setting PEEP [17]. The ventilation is shifted from the inflation the deflation limb of the P-V curve, and this is the intent of this approach. This leads to a greater lung volume with the same PEEP [18]. With incremental PEEP at 11 cm H_2O, tidal recruitment contributes nearly 50% of the maximum mean tidal PV slope [19].

In the last two decades, LUS has proved itself to be efficacious in the diagnosis of many pulmonary conditions. It is also characterized by being non-invasive and it could be performed at bed side [20]. On lung sonogram, ventilated parenchyma full of B-lines are often detected in contiguity with consolidated regions. Although it may indicate normal physiological findings, the number of B lines increases in the cases of interstitial lung diseases, and its density shows a positive correlation with the degree of thickening. Hence, LUS is considered to be a sensitive tool on evaluating interstitial lung thickening [21].
Due to the previously mentioned reasons, LUS was used for mapping lung recruitment during mechanical ventilation or recruitment maneuvers (application of 40–50 mbar of pressure in airways for 20–30 s) [22].

Our results agreed with Bouhemad et al. who conducted a study to compare P-V curves with LUS in 40 cases diagnosed with ARDS or ALI at PEEP of 0 and 15 cm H_2O. there was a strong correlation between US reaeration score and PEEP-induced lung recruitment assessed by P-V curves. Authors concluded that bed side LUS could be used to estimate PEEP-induced lung recruitment [11].

Another study reported that LUS could be applied to detect the degree of atelectasis during laparoscopic procedures. Besides, LUS findings were significantly related to oxygenation parameters (especially Pao2/Fio2 ratio) [23]. Acosta et al. found significant agreement between LUS and magnetic resonance imaging on assessment of cases with atelectasis [24].

Our results agreed with Ferrando et al. who investigated 13 patients undergoing one lung ventilation. They found that individualized decremental PEEP had better higher arterial oxygenation (306 vs 231mmHg, p= 0.007) and better static compliance (P<0.001) than standardized PEEP 5cm H_2O. These improvements were maintained during the procedure till the end of OLV [25].

Furthermore, as physicians can see lung changes when using PEEP, a real-time feedback is obtained and it could be used for the treatment of atelectasis [26]. It could be also used to monitor the response to PEEP titration and recruitment maneuvers [27]. A previous study reported that LUS is as efficacious as lung computerized tomography (CT), and there was a significant correlation between these two radiological modalities [26].

In animal models, Michelet et al. evaluated the effect of PEEP on respiratory mechanics and oxygenation index during OLV. They showed that the application of PEEP (5–10cm H_2O) improved oxygenation. However, 15cm H_2O PEEP was associated with worsened oxygenation as alveolar overdistension causes blood shifting towards the nonventilated areas [28].

This was also confirmed by another study which reported that 4 to 5 cm H_2O of PEEP improved oxygenation during OLV, but the reverse occurred while increasing PEEP level to 8 to 10 cm H_2O [15]. Leong and his colleagues reported no significant differences in oxygenation with PEEP levels 0, 5, 8, and 10 cm H_2O during OLV [29].
In a previous meta-analysis conducted by Breil et al, a total of 2299 cases with ARDS were analyzed. Authors reported improvement in both lung aeration and clinical outcomes on applying higher PEEP values compared to those proposed by the ARDS Network [30].

During two-lung ventilation, selective PEEP application to the dependent lung with the chest closed in the lateral position can improve both oxygenation and dependent lung compliance [32]. It has been previously assumed that the normal configuration of lung compliance curve could be noticed during OLV, and the ventilated lung could move to a different FRC on this curve [1].

A previous study reported that the efficacy of PEEP on oxygenation and pulmonary mechanics relies on the interaction between PEEP and auto-PEEP, which in turn depends on patient mechanical characteristics [32].

The common limitations of ultrasound include its inability detect lung hyperinflation which couldn't be observed in current study. However, static compliance and driving pressure are slightly higher in LUS group but not of statistical significance. This might need larger sample size in future studies depending on lung compliance or driving pressure as primary outcomes. The second limitation is lateral decubitus that interfere with ultrasound examination of lateral compartments of the lung. We thought that this is of limited value as the posterior and basal parts are more liable to collapse that need to be recruited. The third limitation is that intrinsic PEEP wasn't calculated. Intrinsic PEEP develops in most patients undergoing thoracic surgery and one lung ventilation.

Conclusion

Based on results of this concurrent study, we concluded that LUS as effective tool in titration of PEEP during OLV in thoracic surgery. Its intraoperative use was associated with improvement of both oxygenation and lung compliance as PEEP obtained through best lung compliance.

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