The Egyptian Journal of Hospital Medicine (October 2022) Vol. 89, Page 5301- 5309

Individualized versus Conventional Positive End-expiratory Pressure during One Lung Ventilation in Thoracic Surgeries: A Randomized Controlled Study

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ABSTRACT

Background: Postoperative pulmonary problems from thoracic procedures are more likely to occur, which may lead to higher morbidity, a longer hospital stay, higher expenses, and a higher fatality rate.

Objective: This study was done to compare efficacy of using either individualized or the conventional positive end-expiratory pressure (PEEP) for one-lung ventilation on postoperative pulmonary complications.

Patients and Methods: This prospective randomized controlled study was done on 116 patients of age between 18 and 70 years with American Society of Anesthesiologists physical status II to Ш of either sex who underwent elective thoracic surgeries using one-lung ventilation. Patients were allocated randomly to either conventional PEEP group in which patients underwent thoracic surgeries using conventional PEEP (5 cmH_2O) or individualized PEEP group in which patients underwent thoracic surgeries using individualized optimal PEEP which produces the best static lung compliance.

Results: The incidence of postoperative pulmonary complications (PPCs) was lower in individualized PEEP group (12.1%) compared to conventional PEEP group (34.5%) with p (0.004). The most common complication incidence was lung collapse, which was greater in the conventional PEEP group (10.3%) than in the individualized PEEP group (27.6%). Arterial oxygen pressure/fraction of inspired oxygen (PaO2/FiO2) ratio was greater in the individualized compared to conventional PEEP group ($p < 0.001$). There were no significant differences in incidence of pneumonia, pleural effusion, pneumothorax, ARDS, or pulmonary embolism.

Conclusion: Using individualized PEEP in patients receiving one-lung ventilation for thoracic surgeries resulted in decreased incidence of postoperative pulmonary complications, lower postoperative lung aeration score, better intraoperative respiratory mechanics, and oxygenation with no significant changes in hemodynamics.

Keywords: Individualized PEEP, Conventional PEEP, One Lung Ventilation, Pulmonary Complications.

INTRODUCTION

Postoperative pulmonary complications (PPCs) are accompanied with higher morbidity, prolonged hospital stay, increased costs of healthcare, and even higher mortality rates. PPCs have been related to a number of independent risk factors, including, patient health issues like anemia, smoking, and age, as well as surgical techniques and anesthetic management **(1).**

Thoracic surgeries are more likely to result in PPCs due to many variables including patient related factors, the surgery itself, and other factors, such as ventilation-induced lung injury **(2).** Barotrauma due to repeated opening and closure of alveoli together with the inflammatory process of the lung may be the explanation of ventilator-induced lung injury **(3).**

During one-lung ventilation (OLV), the ventilation of one lung is interrupted while the perfusion persists, so oxygenation is a major challenge during OLV **(4).** During thoracic procedures, surgical manipulation, mediastinal displacement, and chest immobility are additional factors that might cause PPCs. When compared to other forms of surgery, thoracic surgery results in higher pressures in the dependent lung and the development of atelectasis **(5).**

The principal factors that contribute to ventilation-induced lung injury as atelectrauma, and overdistention seem to be reduced by lung protective ventilation, hence minimizing PPCs. Positive end-expiratory pressure (PEEP) and a lower tidal volume are the two key elements of lung protective ventilation, which were identified and studied in the intensive care unit (ICU) patients who had acute respiratory distress syndrome (ARDS). This strategy has been demonstrated to may be suitable for healthy lungs **(6).**

PEEP should be chosen based on the patient's unique data, patient position, and surgical approach. During general anesthesia, individual titration of PEEP offers a number of advantages, including; improving respiratory system mechanics, distribution of ventilation, and oxygenation **(7).** PEEP is adjusted through titration to the level of optimal static compliance that allows the lungs to remain open, leading to a more individualized PEEP adjustment **(8).** To our knowledge, the impact of individualized PEEP on PPCs is currently unknown. This study aimed to evaluate the effects of individualized versus conventional PEEP during one-lung ventilation on postoperative pulmonary complications (**the primary outcome).** We hypothesized that using individualized PEEP is superior to conventional PEEP in decreasing postoperative pulmonary complications during one-lung ventilation in thoracic surgeries.

PATIENTS AND METHODS

This prospective randomized controlled study was done at Mansoura University Hospital over 16 months starting in March 2020. This study included 116 patients of age between 18 and 70 years with American Society of Anesthesiologists physical status (ASA) II to Ш of

Received: 14/6/2022
Accepted: 22/8/2022

either sex who underwent elective thoracic surgeries using one-lung ventilation.

Ethical consent:

The study was approved by local Institutional Research Board (IRB), in Mansoura University Hospital/Egypt (MD.20.01.267). Patients were interviewed and written informed consents were obtained from the patients to be a part of our research. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Exclusion criteria: We excluded obese patients (BMI ≥ 35 Kg/m^2), patients with moderate to severe cardiac disorders (NYHA class Ш, IV), patients with chronic liver disease (Child B and C), patients with chronic kidney disease (serum creatinine >1.5 mg/dl), patients with severe chronic obstructive pulmonary disease (FEV1/FVC ≤ 50% of predicted value), bronchial asthma, subjects who refused to share in the study, emergency surgery and redo surgery.

Randomization: Eligible 116 patients were randomly allocated in sequentially numbered, opaque, sealed envelopes using computer-generated randomization software to either individualized PEEP group or conventional PEEP group:

1. **Conventional PEEP group (N = 58 patients):** Patients underwent thoracic surgeries with one lung ventilation using conventional PEEP (5 cmH_2O).
2. **Individualized PEEP group (N = 58 patients):** Patients underwent thoracic surgeries with one lung ventilation using individualized optimal PEEP, which produces the best static lung compliance.

Anesthetic management:

All patients were assessed on the day before surgery by history taking, physical examination , basal laboratory investigations, ECG and CT chest.

As soon as the patient entered the operating room, routine vital signs (noninvasive arterial blood pressure, pulse oximetry, and electrocardiography monitoring) were applied and basal values were recorded. Peripheral I.V line (18-20G) was inserted and all patients received a single dose of prophylactic antibiotic after sensitivity test and intravenous (I.V) Ringer solution was infused (2-4 ml /kg/hr.). Radial artery was cannulated and a basal sample was collected for arterial blood gases (ABG) analysis (basal). After 5 minutes of breathing 100% oxygen, induction of anesthesia was done with l-2 µg/kg fentanyl, 1.5 mg/kg propofol, and 0.5 mg/kg atracurium. A properly sized double-lumen tube was used to intubate the trachea (37F for males and 35F for females). Bronchoscopy was used to confirm the position of the tube in both supine and lateral positions. Volume-controlled ventilation (VCV) with square-wave flow was used to ventilate the patient's lungs during two-lung ventilation (TLV) and one-lung ventilation (OLV). During TLV, tidal volume was 8 mL/kg of the predicted body weight (PBW) maintaining a plateau pressure (P plateau) no more than 30 cmH_2O, (PBW = 45.5+ 0.905* (height in cm) - 152.4) for women, and = 50.0 + 0.905* (height in cm) -152.4) for men (9).

The inspiratory-to-expiratory ratio (I:E) was adjusted to be 1:2 with 10% end-inspiratory pause and the respiratory frequency was modified to keep end-tidal carbon dioxide ($EtCO_2$) level between 35-40 mmHg. The fraction of inspired oxygen (FiO_2) was set at 40%. All patients had an initial PEEP level of 5 cmH_2O during two lung ventilation. Isoflurane at a minimum alveolar concentration (MAC) of 1-1.5 was used to maintain anesthesia in all patients. At the beginning of OLV, we reduced tidal volume to 6 ml/kg of PBW and respiratory frequency was modified to keep end-tidal carbon dioxide ($EtCO_2$) between 35-40 mmHg. All patients in both groups were subjected to a recruitment maneuver using driving pressure of 30 cmH_2O for 30 seconds then the patient was allocated to one of two groups; **Conventional PEEP group:** PEEP was adjusted at 5 cmH_2O. **While in the Individualized PEEP group:** PEEP was adjusted in a decremental manner starting with PEEP of 14 cm H_2O and then decreased in 2 cmH_2O decrements each lasting for 10 respiratory cycles provided that plateau pressure is < 30 cmH_2O until reached optimal PEEP (the PEEP value that corresponds to the highest possible static lung compliance guided by pressure-volume loop). If the plateau pressure was ≥ 30 cmH_2O the tidal volume decreased by 1 ml / kg PBW until the plateau pressure became < 30 cmH_2O.

If accidental intraoperative hypoxemia (SPO_2 < 90%) occurred the following rescue strategy would be followed: Apply recruitment maneuver, increase FiO_2 in steps of 0.1 up to 1, increase PEEP incrementally; 2 cmH_2O in each increment, apply CPAP to non-ventilated lung up to 20 cmH_2O and clamp the pulmonary artery by the surgeon. All patients received standard analgesia protocol in the form of I.V meperdine 0.5 mg/kg, ketolac 30 mg, and paracetamol 10 mg/kg. At the end of the surgery, re-expansion of both lungs was done by the same manner of recruitment maneuver, return to TLV with the same parameter before OLV. Residual neuromuscular blockade was reversed with 40 µg/kg neostigmine and 20 µg/kg atropine. After the patients fulfilled the extubation criteria (sustained eye opening, sustained head, sustained leg lift, and sustained hand grip for 5 seconds), they were extubated and transferred to Intensive Care Unit (ICU) and then discharged to the ward.

Primary outcome:

Incidence of postoperative pulmonary complications such as pneumonia, pneumothorax, pleural effusion, atelectasis, pulmonary embolism, respiratory failure, and acute respiratory distress syndrome (ARDS) within 5 days postoperatively.

Pneumonia defined as (10):

1. Chest radiograph showing new or progressive infiltrates.
2. New or changed sputum, tachypnea, hypoxia.
3. Fever (> 38 °C) or leukocytic count (< 4000 or ≥12,000 WBC/mm^3). Pleural effusion defined as obliteration of the costophrenic angle or loss of the sharp silhouette of the hemidiaphragm on the nonoperative side on chest radiograph or ultrasound. Atelectasis is described as opacities seen on chest radiographs that cause the hilum, mediastinum, or hemidiaphragm to be shifted toward the affected area**(1)**. Pulmonary embolism as pulmonary arteriogram documenting thrombus **(2)**. Respiratory failure causing ventilator dependence ≥24 h postoperatively or noninvasive ventilation or need for reintubation **(11)**. And acute respiratory distress syndrome (ARDS) according to Berlin definition of ARDS **(12)**: a- Acute onset over 1 week or less, b- Bilateral opacities and pulmonary edema, c- $PaO_2/Fi\ O_2$ ratio <300 mmHg with PEEP (or CPAP) 5 cmH_2O or more, d- Must not be fully explained by fluid overload or cardiac failure.

Secondary outcomes:

1- Mechanical ventilation settings (Tidal volume (TV), Respiratory rate (RR), and PEEP.

2- Hemodynamic monitoring as heart rate and invasive mean blood pressure were monitored at (Basal, 10 min after TLV, 10 min after application of PEEP after OLV, 60 min after OLV, and during TLV before extubation) and the number of patients who required ephedrine (5 mg bolus would be given if mean BP was decreased ≥ 20 % of the basal value after PEEP application).

3- Respiratory mechanics (peak pressure, plateau pressure, "driving pressure = plateau pressure minus PEEP" and static compliance) and PaO_2/FiO_2 during TLV (10 min after intubation), 10 min after application of PEEP during OLV, then every 30 min after OLV, after resuming TLV and at end of TLV just before extubation.

4- Lung aeration score: In non operative dependent lung using lung ultrasound examination in the postoperative period (One hour and 24 hrs after operation), an ultrasound score ranging between 0 and 18 was calculated as the sum of each region. For each region, points were allocated depending on the worst U/S pattern observed. Increase in the score means decrease in aeration, 0 = normal, 1 = well separated B-lines, 2 = coalescent B-lines, 3 = consolidation. **(13)**. All ultrasound scans were done by another anesthesiologist who is experienced in lung U.S, using (Vivid T8 R2.5 GE Healthcare, USA). According to the lung ultrasound examination technique described by **Acosta *et al.* (14)**. Examination of patients were done in the supine position. Using two axial lines (one above the diaphragm and the other 1 cm above the nipples) and three longitudinal (parasternal, anterior, and posterior axillary), the non-operative hemithorax was divided into six regions. The following signals were evaluated in each region and the probe was parallel to the ribs using a two-dimensional image: A and B lines, lung sliding sign, juxtapleural consolidation, and air bronchograms. The 6 lung regions were examined sequentially from anterior to posterior, and from cranial to caudal **(15)**.

5- Duration of ICU and hospital stay.

6- One month re-admission and mortality.

Sample size calculation and Statistical analysis:

Calculation of sample size of patients was done with using G*POWER program (version 3.1.9.2). The α -error level was fixed at 0.05, B -error 0.2 (power = 80%), 106 cases were needed to decrease postoperative pulmonary complications by 25%. Allowing 10% dropout, 116 cases were needed to detect the minimal clinical difference between the two groups and was based on previous study (16).

Statistical analysis

The statistical analysis of data was achieved using Statistical Package for the Social Sciences (SPSS) Software (Version 26, SPSS Inc., IL, USA). For continuous data, Kolmogorov-Smirnov test was used to assess the normality, and then analyzed with the Student t-test. Analysis of data that did not have a normal distribution, as well as ordinal data was done with the Mann-Whitney U test. For categorical data, Chi-square test or Fisher's exact test was used. Data were presented in the form of mean ± SD (standard deviation) for parametric data and median (range) for nonparametric data. At a 95% confidence level, any difference or change with a probability (*P*-value) less than 0.05 was considered to be statistically significant.

RESULTS

The total number of patients included in this study was 121 patients. There were three patients excluded from the study as one patient had a major cardiovascular problem and two patients with major hepatic problems. Two patients refused the written informed consent.

One hundred and sixteen patients of age ranging from (18 - 70) years of either sex who underwent thoracic surgeries using one-lung ventilation were enrolled in the study. The patients were randomly allocated into two groups; conventional and individualized PEEP group (n= 58 per group) (Fig. 1). The two groups did not differ with respect to demographic data (age, sex, weight, height, and BMI), associated comorbid diseases (DM, hypertension, COPD), and the duration and type of surgery **(Table 1)**.

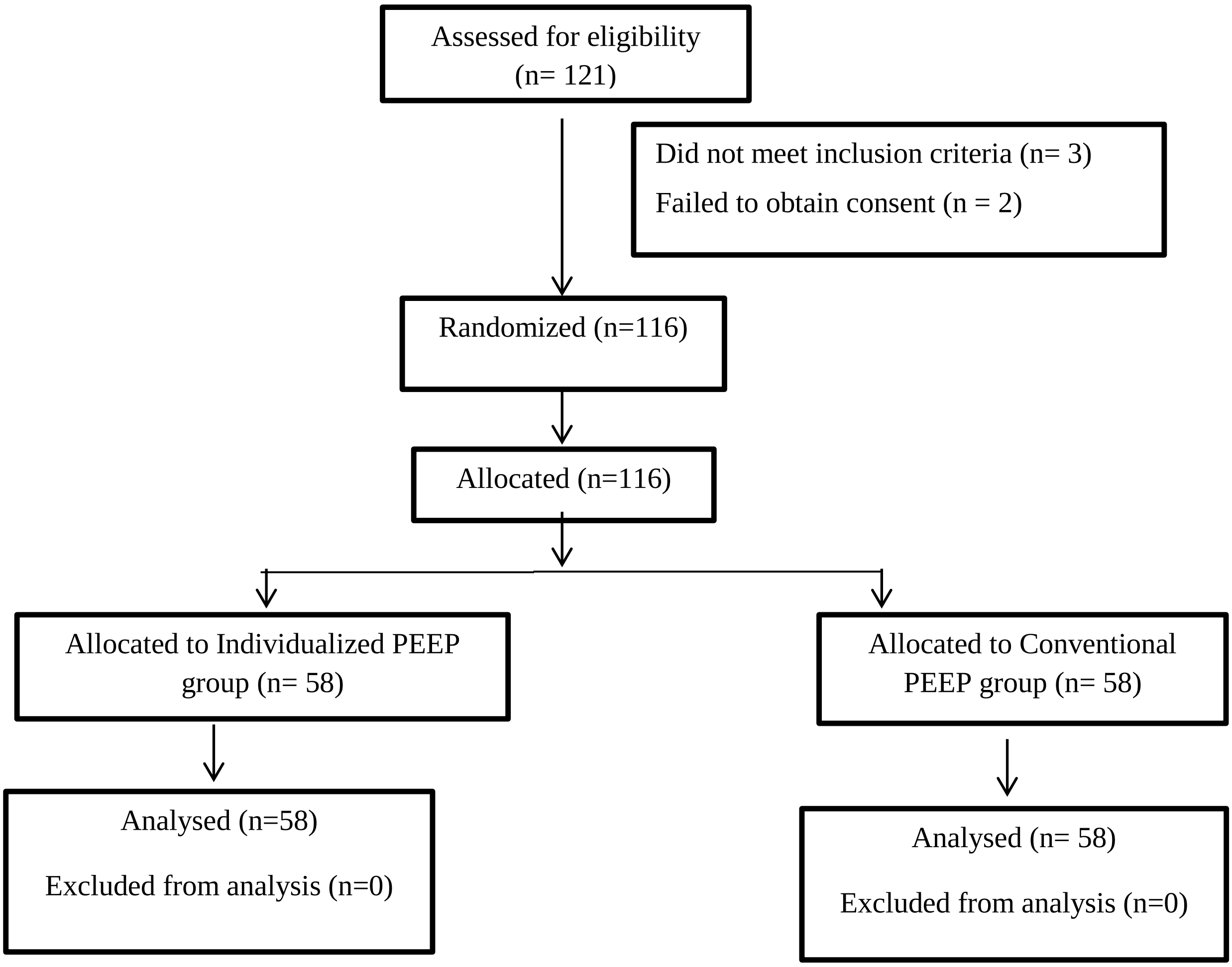

Figure (1): Consort flow chart of the studied groups

Table (1): Demographic data, type of surgery, duration of surgery, comorbidities of studied groups

Variable	**Conventional PEEP group** (N=58)	**Individualized PEEP group** (N=58)	**P- value**
Age (years)	54.28±10.39	53.59±11.05	0.73
Weight (Kg)	75.69±4.07	74.93±4.67	0.353
Height (cm)	169.74±4.83	170.17±5.79	0.664
BMI (Kg/m^2)	26.28±1.37	25.88±1.22	0.097
Sex			
Male:	27(46.6%)	29(50%)	0.71
Female:	31(53.4%)	29(50%)	
Comorbid diseases			
COPD	2(3.4%)	3(5.2%)	1
DM	7(12.1%)	9(15.5%)	0.59
Hypertension	5(8.6%)	7(12.1%)	0.542
Type of surgery			
Bullectomy	7(12.1%)	9(15.5%)	0.59
Segmentectomy	22(37.9%)	19(32.8%)	0.56
Lobectomy	23(39.7%)	24(41.4%)	0.85
Thymectomy	4(6.9%)	3(5.2%)	1
Decortication	2(3.4%)	3(5.2%)	1
Duration of surgery(min)	200.86±42.05	197.33±37.94	0.636

Data are presented as means ± standard deviation (SD), number and percentage (%), N = number
BMI (body mass index), Chronic obstructive pulmonary disease (COPD), DM (diabetes mellitus)

However, **table 2** shows that differences between the two groups as regard pneumonia, pleural effusion, pneumothorax, ARDS, and pulmonary embolism were not of statistically significance, but there was a significant decrease in the incidence of lung collapse and PPCs as a composite in individualized PEEP group. The incidence of PPCs was statistically lower in individualized PEEP group compared to conventional PEEP group.

Table (2): Incidence of postoperative pulmonary complications (PPCs) changes of the studied groups

Variable	**Conventional PEEP group** (N=58)	**Individualized PEEP group** (N=58)	**P- value**
Pneumonia	4(6.9%)	2(3.4%)	0.402
Pleural effusion	4(6.9%)	1(1.7%)	0.364
Pneumothorax	1(1.7%)	0(0%)	1
Pulmonary embolism	1(1.7%)	0(0%)	1
Atelectasis	16(27.6%)	6(10.3%)	**0.018***
ARDS	0(0%)	0(0%)	1
Respiratory failure	3(5.2%)	0(0%)	0.243
PPCs	20(34.5%)	7(12.1%)	**0.004***

Data are presented as number and percentage (%), *: Significant, ARDS: Acute Respiratory Distress Syndrome, PPCs: Postoperative Pulmonary Complications.

No significant difference was detected between the two groups as regards tidal volume and respiratory rate during TLV and OLV, but PEEP was statistically higher in individualized PEEP group during OLV. Heart rate (HR), and mean arterial blood pressure (MAP) that were measured intraoperatively showed no statistically significant differences between the two groups and the two groups did not differ in need of ephedrine after RM and application of PEEP **(Table 3)**.

Table (3): Mechanical ventilation settings **(**Tidal volume (TV), Respiratory rate (RR), PEEP) and patients needed ephedrine

Variable		**Conventional PEEP group** (N=58)	**Individualized PEEP group** (N=58)	**P- value**
Tidal volume (TV ml)	**TLV**	504.74±48.31	509.91±54.99	0.592
	OLV	378.45±40.66	378.88±51.67	0.96
Respiratory Rate (RR breath/min)	**TLV**	12.38±0.79	12.34±0.76	0.811
	OLV	16.47±1.06	16.21±1.07	0.195
PEEP (**cmH_2O)**	**OLV**	5±0.41	8.26±0.98	**< 0.001***
Patients needed ephedrine		1(1.7%)	3(5.2%)	0.618

Data are presented as means ± standard deviation (SD), number and percentage %, *: Significant

As regards the respiratory mechanics, peak inspiratory pressure and plateau pressure during TLV and OLV showed no significant differences between both groups, but there was a significant decrease in driving pressure and increase in static compliance during OLV in individualized PEEP group **(Table 4).** However, the study demonstrated that PF ratio 10 minutes after application of PEEP and after 60 minutes of OLV was higher in individualized PEEP group during OLV but not during TLV (**Table 5**).

Table (4): Respiratory mechanics (Peak inspiratory pressure (PIP), Plateau pressure (P plateau), Driving pressure and static compliance)

Variable		**10 min after TLV**	**10 min after application of PEEP after OLV**	**30 min after OLV**	**60 min after OLV**	**Resume of TLV**	**TLV before extubation**
PIP (cmH$_2$O)	**Conventional PEEP group** (N=58)	19.72±2.54	27.98±2.02	28.19±2.32	28.26±2.08	20.12±2.69	20.26±2.3
	Individualized PEEP group (N=58)	19.83±2.25	28.40±1.97	28.74±1.93	28.64±1.83	19.47±2.08	19.66±2.22
	P- value	0.817	0.267	0.1680	0.3	0.146	0.154
P. plateau (cmH$_2$O)	**Conventional PEEP group**	15.97±2.18	23.19±1.63	23.52±1.54	23.50±1.41	15.84±2.32	16.05±2.13
	Individualized PEEP group	15.67±1.92	22.48±1.72	22.64±1.71	22.60±1.7	15.14±1.7	15.36±1.69
	P- value	0.293	0.707	0.879	0.897	0.064	0.056
Driving pressure (cmH$_2$O)	**Conventional PEEP group**	10.97±2.18	18.19±1.63	18.52±1.54	18.50±1.41	10.84±2.32	11.05±2.13
	Individualized PEEP group	10.67±1.92	14.22±2.11	14.38±2.06	14.34±2.14	10.14±1.7	10.36±1.69
	P- value	0.445	< **0.001***	< **0.001***	< **0.001***	0.064	0.056
Static compliance ml/(cmH$_2$O)	**Conventional PEEP group**	47.88±10.5	20.95±2.77	20.55±2.58	20.56±2.56	48.75±11.66	47.43±10.29
	Individualized PEEP group	49.18±9.57	27.28±5.89	26.86±5.13	27.03±5.63	51.61±9.73	50.40±9.02
	P- value	0.489	< **0.001***	< **0.001***	< **0.001***	0.155	0.102

Data are presented as means ± standard deviation (SD), *: Significant

Table (5): PaO$_2$/FiO$_2$ ratio (PF ratio) changes of the studied groups

Pao2/FiO$_2$ ratio	**Basal**	**10 min after TLV**	**10 min after application of PEEP after OLV**	**60 min after OLV**	**Resume of TLV**	**TLV before extubation**
Conventional PEEP group (N=58)	409.85±31.23	433.75±52.5	194.05±29.57	218.31±32.15	417.67±47.04	432.28±48.27
Individualized PEEP group (N=58)	404.68±33.09	435.95±45.61	225.95±18.28*	243.79±22.66*	427.11±41.1	448.23±45.93
***P*-value**	0.388	0.810	< **0.001***	< **0.001***	0.252	0.071

Data are presented as means ± standard deviation (SD), *: Significant

Postoperative lung aeration score (LAS) was significantly lower in individualized PEEP group when compared to conventional PEEP group. Patients in individualized PEEP group stayed in ICU and hospital for a shorter duration than patients in conventional PEEP group but with no significant difference. During the first month following surgery, no patient in either group died or needed to be readmitted as a result of a pulmonary problem **(Table 6)**.

Table (6): Lung aeration score (0-18 scale) in dependent non operative lung of the studied groups, duration of ICU and hospital stay, one month readmission, and one month mortality of the studied groups

Variable	**Conventional PEEP group** (N=58)	**Individualized PEEP group** (N=58)	**P- value**
Lung aeration score:			
1hr postoperative	1(0-3)	0(0-2)	**< 0.001***
24hrs postoperative	2(1-4)	1(0-3)	**< 0.001***
Duration of ICU stay (hours)	34(20-48)	29(18-46)	0.082
Duration of hospital stay (days)	6(5-8)	6(5-7)	0.091
One month readmission	0(0%)	0(0%)	1
One month mortality	0(0%)	0(0%)	1

Data are presented as median (minimum and maximum), number and percentage (%), *: Significant, ICU: Intensive Care Unit.

DISCUSSION

This study compared the effects of individualized and conventional PEEP during single lung ventilation in thoracic surgeries on postoperative pulmonary complications, intraoperative oxygenation, respiratory mechanics, hemodynamics, postoperative lung aeration score, and postoperative ICU and hospital stay.

One-lung ventilation can result in atelectrauma, barotrauma, volutrauma, and oxygen toxicity, all of which are essential components of ventilator-induced lung injury that cause an increased risk of postoperative pulmonary complications (PPCs) **(17)**. A significant correlation exists between atelectasis and postoperative pulmonary problems. According to evidence, atelectasis is one of the main mechanisms of acute lung injury, it also contributes significantly to postoperative hypoxemia and is linked to prolonged stay in the ICU and hospitals **(18)**. Significant postoperative pulmonary problems including respiratory failure and pneumonia may potentially be exacerbated by atelectasis **(19)**. Postoperative pulmonary problems continue to be the leading factor in prolonged hospital stay and mortality and the management of ventilation during one lung ventilation (OLV) during thoracic surgery is still challenging. PEEP, recruitment techniques (RM), and low tidal volume are all considered to be part of protective lung ventilation. As a result, attempts to lower PPCs are essential to improve the outcome of surgical patients **(20, 21)**. It is believed that reduced tidal volumes reduce intrapulmonary stress and strain. While PEEP, recruitment techniques are aimed to prevent the development of atelectasis and maintain blood oxygenation **(22)**.

The current study demonstrated that during one-lung ventilation, using optimal PEEP has the advantages of lower incidence of postoperative pulmonary complications (PPCs), lower postoperative lung aeration score, better lung mechanics, higher oxygenation index with no significant changes in intraoperative hemodynamics, postoperative ICU and hospital stay.

The incidence of PPCs was lower in optimal PEEP group compared to conventional PEEP group. The most common complication was lung collapse. Its incidence was greater in the conventional PEEP group than in the individualized PEEP group. The two groups did not differ in the incidence of pneumonia, pleural effusion, pneumothorax, ARDS, and pulmonary embolism.

Positive end-expiratory pressure (PEEP) is usually used aiming to limit pulmonary atelectasis, stop the repeated opening and collapsing of alveoli, and so enhance oxygenation. This lowers the risk of atelectasis, mismatch of ventilation to perfusion ratio (V/Q), and hypoxemia. However, improper PEEP settings could result in an increase in pulmonary vascular resistance shifting blood flow to the non-ventilated lung, which could decrease oxygenation during OLV **(23)**.

So, the optimal level of PEEP during OLV and PEEP titrating strategy remains to be controversial. The optimal PEEP is the PEEP setting that produces the maximum compliance of the respiratory system and lower incidence of postoperative pulmonary complications **(24-26)**. Moreover, **Belda *et al.*** concluded that, lower incidence of PPCs, lower driving pressure, and better dynamic compliance in patients who were subjected to an open-lung approach (low VT, RM, and a decremental titration of PEEP to reach individualized PEEP) during one-lung ventilation compared to pre-open-lung approach **(6)**.

In the current study the driving pressure during OLV was much lower in individualized PEEP group than in conventional PEEP group. Individualized PEEP group exhibited better static lung compliance than conventional PEEP group during OLV. Peak and plateau airway pressure measurements in both groups showed no significant difference, also better oxygenation profile was observed in individualized PEEP group than conventional PEEP group during OLV and after resuming TLV.

A study done by **Park *et al.*** evaluated the optimal PEEP that produces the lowest driving pressure in comparison to 5 cmH_2O of PEEP in 292 patients prepared for thoracic surgeries and their effect on PPCs and lung mechanics during single lung ventilation. They found that optimal PEEP was associated with less PPCs and better lung mechanics **(27).**

Ferrando *et al.* who investigated individualized PEEP (10 ± 2 cmH_2O) versus standardized PEEP (5 cmH_2O) during one-lung ventilation found that the results favor individualized PEEP as regards improvement in oxygenation (PaO_2 306 vs. 231 mmHg, P = 0.007) and lung mechanics compared to a standardized 5 cmH_2O of PEEP **(28).**

Using a low tidal volume of 5 ml/kg ideal body weight and individualized PEEP (5-8 cmH_2O) as a protective ventilation strategy versus nonprotective ventilation using a higher tidal volume of 10 ml/kg ideal body weight with zero PEEP was investigated by **Marret *et al.*** and they found a lower incidence of PPCs (13.4% in optimal PEEP group vs. 22.2% in conventional PEEP group P= 0.03), better lung mechanics and shorter hospital stay **(29).**

In addition, the study done by **Choi *et al.*** included three groups, the first group with no PEEP, the second group with PEEP 8 cm H_2O, the third group with PEEP 8 cm H_2O after recruitment maneuver and they found better oxygenation and lung compliance in the third group with no significant difference in hemodynamics **(30).**

In addition to, the study done by **Rauseo *et al.*** compared optimal PEEP after recruitment maneuver (open lung approach) and zero PEEP before recruitment maneuver that was achieved in one-lung ventilation for thoracic surgery and showed higher oxygenation index and lung mechanics without significant change in hemodynamics **(31).**

However**, Liu *et al.*** compared one-lung ventilation with optimal PEEP (9-13 cm H2O) versus conventional PEEP (5 cm H_2O) in elderly patients having thoracoscopic surgery and they found improved lung mechanics and oxygenation in optimal PEEP group with no significant difference in PPCs (34% in conventional PEEP group vs. 30% in optimal PEEP group) or hospital stay **(32).**

The cause of difference with our results as regard PPCs may be due to different type of surgery or shorter duration of surgery.

LIMITATIONS

This study has limitations; first, it did not include measurement of plasma level of inflamatory mediators to obtain the correlation with lung injury during one-lung ventilation, second, it did not follow up patients for a long duration to detect delayed postoperative pulmonary complications and mortality, and third, it did not include measurement of shunt fraction due to the absence of a pulmonary artery catheter.

CONCLUSION

Using individualized PEEP in patients receiving one-lung ventilation for thoracic surgeries has the advantages of lower incidence of postoperative pulmonary complications, lower postoperative lung aeration score, better intraoperative respiratory mechanics, and oxygenation with no significant changes in hemodynamics.

RECOMMENDATIONS

Measurement of plasma levels of inflammatory mediators to determine the correlation with lung injury during one-lung ventilation and follow up patients for a long duration to detect delayed postoperative pulmonary complications and mortality in studies with a larger sample size.

Financial support: The study did not receive any form of financial support.

Conflict of interest: No conflict of interest during this work.

Author contribution: Authors contributed equally in the study.

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