



Effect of Stepwise Lung Recruitment Maneuver on Oxygenation, Lung Mechanics and Lung Injury Biomarkers During Lung Resection Surgery: A Prospective Randomized Controlled Single Blinded Study

Dalia Ahmed El Sayed El Hefny^a, Mohamed Ibrahim Mohamed^{id b}, Shahira Ahmed Yousef El-Metainy^{id b}, Mohamed Moustafa Ibrahim Abdelaal^c and Yasser Mohamed Osman^{id b}

^aAnaesthesia and Surgical Intensive Care, Kafrelsheikh Faculty of Medicine, Kafrelsheikh, Egypt; ^bAnaesthesia and Surgical Intensive Care, Alexandria Faculty of Medicine, Alexandria, Egypt; ^cCardiothoracic Surgery, Kafrelsheikh Faculty of Medicine, Kafrelsheikh, Egypt

ABSTRACT

Background: One lung ventilation for lung resection surgery may affect oxygenation, impair lung mechanics and increase the incidence of acute lung injury. Lung recruitment maneuver may improve these conditions.

Settings and Design: This study was a prospective randomized controlled single blinded clinical trial.

Methods: Forty patients scheduled for elective lung resection surgeries using one lung ventilation under general anaesthesia were randomly allocated into two groups. Control (C) group was subjected to conventional mechanical ventilation of tidal volume of 8 ml/kg and 5 ml/kg for total lung ventilation (TLV) and one lung ventilation (OLV), respectively, and PEEP of 5 cmH₂O and (LR) group which was subjected to stepwise lung recruitment twice: The first lung recruitment (LR1) was performed after (OLV) to the dependent lung, while the second lung recruitment (LR2) was performed after resuming (TLV). Arterial blood gases, lung mechanics and serum tumor necrosis factor alpha were recorded at multiple time points during the study. The proposal and raw data were registered on PACTR as **PACTR202001518687696**.

Results: There was a significant decrease in PaO₂/FIO₂ during OLV baseline in comparison to TLV baseline ($P = < 0.001^*$) in both groups. While, in LR group, there was a significant increase in PaO₂/FIO₂ and dynamic compliance during OLV-20 min after recruitment ($P = < 0.001^*$), during TLV-20 min after recruitment ($P = < 0.001^*$) and during TLV-end ($P = < 0.001^*$). TNF- α level was significantly higher in control group 1 h after surgery and 24 h postoperative.

Conclusion: Stepwise lung recruitment maneuver improved oxygenation parameters and lung mechanics during lung resection surgery and decreased the expression of lung injury biomarkers.

Abbreviations: OLV: one lung ventilation; TLV: total lung ventilation; RM: recruitment maneuver; LR: lung recruitment; TNF- α : tumor necrosis factor alpha; VCV: volume controlled ventilation; PCV: pressure controlled ventilation; VT: tidal volume; FIO₂: fraction of inspired oxygen; ALI: acute lung injury; ppoFEV1%: predicted postoperative forced expiratory volume in 1 s; BAL: Bronchoalveolar lavage.

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1. Introduction

Lung resection surgery is one of the most commonly performed thoracic surgical procedures [1]. One-lung ventilation (OLV) is regularly used to facilitate surgical exposure and to isolate and protect the lungs throughout the surgery [2].

An inevitable intrapulmonary shunt during OLV arises as a result of non-dependent lung collapse and increased atelectatic regions in the dependent lung, resulting in hypoxemia and impairment of gas exchange and activation of hypoxic pulmonary vasoconstriction aiming to reduce the shunt [3].

During OLV, a variety of inflammatory cytokines are released in response to a variety of pathophysiological disturbances such as high airway pressures, elevated pulmonary capillary pressure and pulmonary

alveolar resistance, compression of alveolar vessels, alveolar cell stretch, over-distension and cyclic alveolar collapse, ventilation/perfusion mismatch with shunt, all of which can trigger local or systemic inflammatory responses [4,5].

Lung protective ventilation and lung recruitment maneuvers are utilized during OLV to limit the severity of acute lung injury and postoperative pulmonary complications [6]. Although lung-protective ventilation can help to minimize acute lung injury, reduced tidal volume can lead to alveolar collapse, so lung recruitment maneuver is regarded the best method for increasing oxygenation, resolving ventilation-perfusion mismatch, improving lung mechanics and reversing atelectasis during one lung ventilation [7].

CONTACT Dalia Ahmed El Sayed El Hefny daliaelhefny255@gmail.com Anaesthesia and Surgical Intensive Care, Kafrelsheikh Faculty of Medicine, Kafrelsheikh, Egypt

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Therefore, the primary aim of the present study was to study the effect of stepwise lung recruitment maneuver in patients undergoing lung resection surgery on oxygenation parameters, while the secondary aim to evaluate the effect of recruitment on lung mechanics and lung injury biomarker represented by tumor necrosis factor alpha (TNF- α).

2. Patients and methods

Agreement of the Ethical Committee of Alexandria Faculty of Medicine (IRB-NO: 00007555- FWA-NO: 00018699) and trial registry on PACTR as **PACTR202001518687696** and a written informed consent from all the patients were obtained. The present study was carried out in Alexandria University hospitals on 40 adult patients, American Society of Anaesthesiologists (ASA) physical status class II–III with age ranged from 20–60 years scheduled for elective lung resection surgeries using one lung ventilation under general anaesthesia. The study was carried out between September 2018 till June 2021.

The exclusion criteria were New York Heart Association III to IV, arrhythmia with unstable haemodynamics, bronchopulmonary fistula, preoperative Hemoglobin < 10 gm/dl, previous contralateral lung resection surgery and predicted postoperative FEV1% (ppoFEV1%) < 40% [8].

The patients were randomly allocated using computer generated sequence numbers, into two equal groups (20 patients in each group) using closed envelope technique in a single blinded manner, where patients did not know in which group, they were allocated. Group (C) control group in which conventional mechanical ventilation was performed without performing lung recruitment maneuver and Group (LR) lung recruitment group was subjected to stepwise lung recruitment maneuver.

Preoperative evaluation was carried, covering proper history taking clinical examination, routine laboratory investigations, arterial blood gases, ECG, echocardiography, chest x ray, CT chest, pulmonary function tests and serum tumor necrosis factor alpha (TNF- α).

On arrival to the operating theatre, a peripheral venous catheter was inserted, and all patients were monitored by standard monitoring using multichannel monitor (AVANCE CS², GE Healthcare, Madison, USA) to display electrocardiogram (ECG) for heart rate (beats/min) and rhythm, oxygen saturation (SpO₂%), non-invasive arterial blood pressure (NIBP) (mmHg) and invasive arterial blood pressure (mmHg) through radial artery catheter after performing modified Allen's test [9]. End tidal CO₂ (ETCO₂) (mmHg) was connected after intubation. A nerve stimulator in AVANCE GE for neuromuscular blockade monitoring and entropy were additionally applied.

Thoracic epidural catheter was inserted at the thoracic interspaces (T5–T6) or (T6–T7) under midazolam sedation of 0.03–0.05 mg/kg. 0.1 ml/kg bolus of epidural infusion of 0.125% of plain bupivacaine in combination with fentanyl (2 microgram/ml) was delivered before surgical incision followed by 0.1–0.2 ml/kg/hour to keep arterial blood pressure and heart rate within 20% of the pre-induction values.

General anaesthesia was induced with fentanyl 2 μ g/kg, propofol 1.5–2 mg/kg and cisatracurium 0.15–0.2 mg/kg intravenously, followed by tracheal intubation using left sided double-lumen endobronchial tube (DLT) size 37–39 French, in which its correct position in supine and lateral position was confirmed using a fiberoptic bronchoscope. Anaesthesia was maintained with isoflurane 1–2% to maintain entropy between 40 and 60 and cisatracurium increments of 0.015–0.02 mg/kg intravenously guided by train of four (TOF) ratio.

Initially, in both studied groups, two lung ventilation with volume controlled ventilation mode (VCV) was performed using tidal volume (8 ml/kg) and initial PEEP of 5 cmH₂O, the inspiratory to expiratory ratio was 1:2 and the respiratory rate was adjusted to keep end tidal CO₂ between 35 and 45 mmHg with maximum airway pressure (P_{max}) of 35 cmH₂O, Followed by One lung ventilation (OLV) to the dependent lung with (VCV), with tidal volume of (5 ml/kg) and PEEP of 5 cmH₂O; with same the inspiratory to expiratory ratio of 1:2 and the same respiratory rate to keep end tidal CO₂ between 35 and 45 mmHg with maximum airway pressure (P_{max}) of 35 cmH₂O in LR group and 30 cmH₂O in control group and inspired fraction of oxygen (FIO₂) was adjusted to maintain oxygen saturation above 95%.

Group (LR) lung recruitment group was subjected to stepwise Lung recruitment twice: The first was performed after the start of one lung ventilation (OLV) in lateral position to the dependent lung, while the second was performed after resuming total lung ventilation (TLV).

Stepwise lung recruitment maneuver was performed with pressure controlled ventilation (PCV), maximum airway pressure (P_{max}) was increased to 38 cmH₂O during recruitment with inspiratory to expiratory ratio of 1:2 and respiratory rate of 12 cycles/min. PEEP was increased in increments of 5 cm H₂O for 3 respiratory cycles in a stepwise manner till reaching 20 cmH₂O lasting for 6 respiratory cycles with a constant driving pressure of 15 cmH₂O above the PEEP. The dynamic compliance, oxygen saturation (SpO₂%) and blood pressure were monitored at each step. This was followed by progressive reduction of PEEP step by step with decrements of 2 cmH₂O where each step lasted for 3 respiratory cycles, until the maximum dynamic compliance is obtained. If signs of overdistension appeared (dynamic compliance

C_{dyn} decreased or decrease in oxygen saturation or severe hypotension) before reaching 20 cmH₂O PEEP, this patient was excluded from the study. During decremental decrease in PEEP, the point at which dynamic compliance C_{dyn} decreased or oxygen saturation decreased by $\geq 1\%$ from the maximum reading observed. This was defined as the derecruitment point and PEEP was returned to the previous step, which was defined as optimal PEEP which was kept all over the surgical period. After lung recruitment maneuver, VCV was resumed with setting the optimal PEEP. Tidal volume and the respiratory rate were modified to keep end tidal CO₂ within the target range. Maximum airway pressure (P_{max}) was adjusted to 35 cmH₂O.

In both groups after resuming total lung ventilation and before the second lung recruitment maneuver in the study group, routine manual hyperventilation to both lungs will be done aiming to inflate the non-dependent lung in all patients.

At the end of surgery, after reversal of neuromuscular blockade with neostigmine (0.04–0.08 mg/kg) and atropine (0.01–0.02 mg/kg), and after recovery from anaesthesia, all patients were extubated and transferred to post-anaesthesia care unit (PACU) with epidural infusion of dose 0.01 ml/kg/hour of 0.125% of plain bupivacaine in combination with Fentanyl 2 microgram/ml. The epidural catheter was removed on the second postoperative day.

Oxygenation parameters (PaO₂/FIO₂ and alveolar-arterial oxygen gradient) and lung mechanics were measured during the following times: in lateral position with TLV, before starting OLV (TLV-baseline), after initiation of OLV (OLV-baseline), 20 min after recruitment during OLV (OLV-20 min LR1), 20 min after recruitment during TLV (TLV-20 min LR2) and at the end of TLV, just before extubation (TLV-end), while serum tumor necrosis factor α (TNF- α) was measured by enzyme-linked immunosorbent assay (ELISA) in (pgml⁻¹) [10] preoperatively, 1 h after surgery and 24 h postoperatively.

2.1. Statistical analysis

The sample size was calculated using G.Power software. It was estimated that a total number of 40 patients were needed to detect at least 10% difference in partial arterial oxygen tension after lung recruitment using alpha error = 5% with 80% power [7].

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The Kolmogorov-Smirnov was used to verify the normality of distribution of variables, and comparisons between groups for categorical variables were assessed using Chi-square test (Fisher Exact). Student t-test was used

to compare two groups for normally distributed quantitative variables. While ANOVA with repeated measures using Post Hoc Test (adjusted Bonferroni). Significance of the obtained results was judged at the 5% level.

3. Results

Forty-nine subjects were assessed for eligibility to participate in this study, 43 patients were enrolled in the study, and 6 patients were excluded for not meeting the inclusion criteria. 3 patients discontinued the intervention in the LR group due to overdistension during the recruitment maneuver. Statistical analysis was done on 40 patients (20 patient in each group) as represented in Figure 1.

Regarding demographic data, duration of the surgery and duration of OLV, there was no statistically significant difference between the two groups as represented in Table 1.

As regards oxygenation parameters as represented in Table 2, There was a significant decrease in PaO₂/FIO₂ during OLV baseline in comparison to TLV baseline in both groups ($P = <0.001^*$), while on comparing both groups, there was a significant increase in PaO₂/FIO₂ in LR group during OLV-20 min after recruitment ($P = <0.001^*$), during TLV-20 min after recruitment ($P = <0.001^*$) and during TLV-end ($P = <0.001^*$) as represented in Figure 2. As regards PAO₂-PaO₂ gradient, there was a significant decrease in PAO₂-PaO₂ gradient in LR group during OLV-20 min after recruitment ($P = 0.002^*$), during TLV-20 min after recruitment ($P = <0.001^*$) and during TLV-end ($P = <0.001^*$).

Regarding lung mechanics as represented in Table 3, there was a significant increase in dynamic compliance in LR group during OLV-20 min after recruitment ($P = <0.001^*$), TLV-20 min after recruitment ($P = <0.001^*$) and TLV-end ($P = <0.001^*$) on comparing both groups. Also, the mean airway pressure was increased significantly in LR group during OLV-20 min ($P = <0.001^*$), TLV-20 min ($P = <0.001^*$) and TLV-end ($P = <0.001^*$), while there was no significant difference in peak pressure and plateau pressure between the two groups at the studied times.

Regarding, serum TNF- α , on comparing both groups, there was a significant increase in TNF α in the control group 1 h after surgery ($P = <0.001^*$) and 24 h postoperative ($P = <0.001^*$) as represented in Table 4.

4. Discussion

The improvement in oxygenation parameters after LR in the present study may be related to a decrease in intrapulmonary shunt by application of constant end

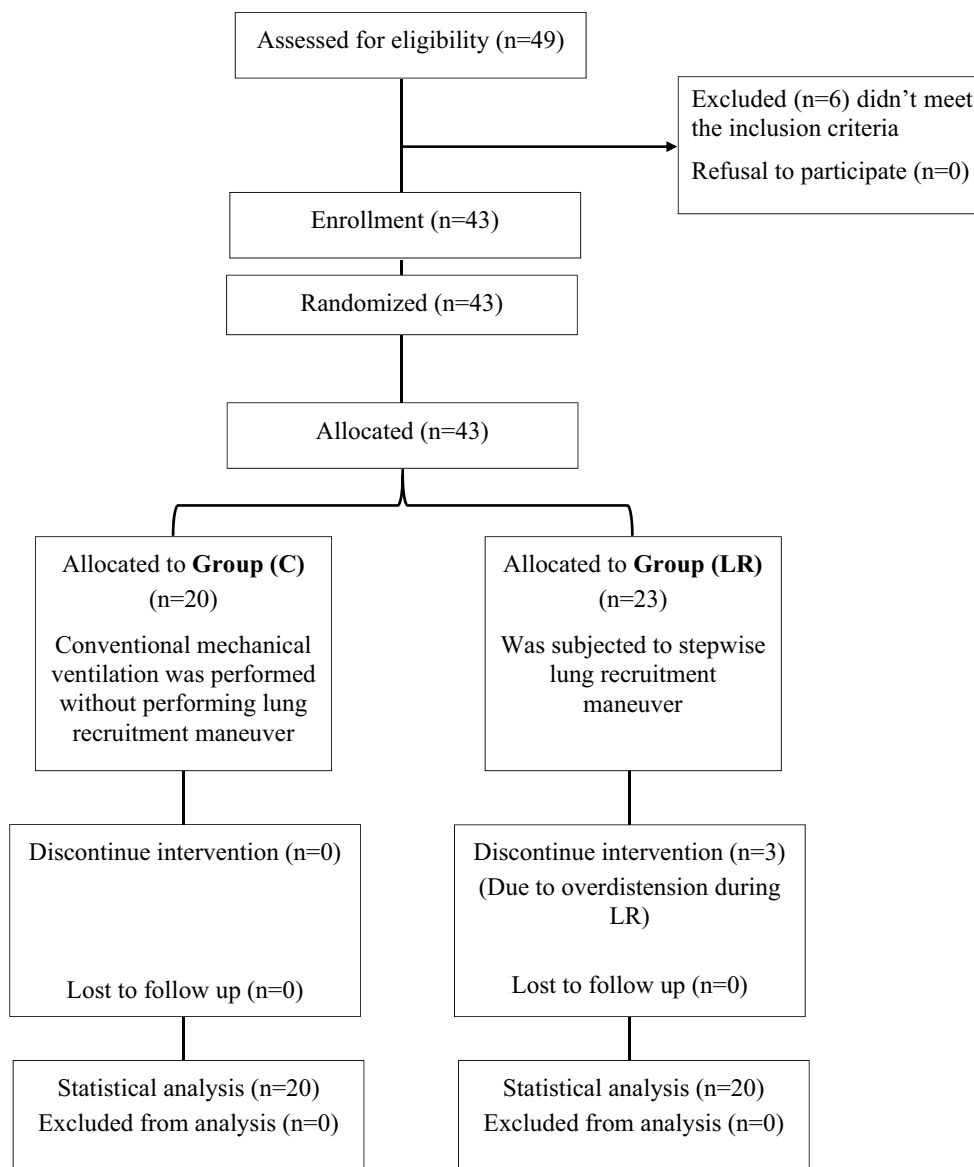


Figure 1. Flow chart of the patients.

Table 1. Comparison between the two studied groups according to demographic data.

Demographic data	Control group (n = 20)	Recruitment group (n = 20)	Test of Sig.	p
Sex				
Male	19 (95%)	17 (85%)	$\chi^2 = 1.111$	^{FE} p = 0.292
Female	1 (5%)	3 (15%)		
Age (years)				
Min.–Max.	34–60	20–60	t = 0.683	0.500
Mean \pm SD.	51.8 \pm 7.5	49.5 \pm 13.4		
Weight (kg)				
Min.–Max.	60–95	54–95	t = 0.902	0.373
Mean \pm SD.	79.2 \pm 11.2	75.8 \pm 12.3		
Duration of surgery (min)				
Min.–Max.	150–240	150–270	t = 1.766	0.086
Mean \pm SD.	179.8 \pm 27.4	198.3 \pm 38		
Duration of OLV (min)				
Min.–Max.	90–150	90–180	t = 1.859	0.071
Mean \pm SD.	113.3 \pm 16.6	125.5 \pm 24.3		

χ^2 : chi square test; FE: Fisher exact; t: Student t-test.

p: p value comparing between the two studied groups.

expiratory pressure which cause less V/Q mismatch due to homogeneous distribution of inspired gas during pressure-controlled recruitment maneuver, reversal of atelectasis.

In agreement with our study, Ferrando et al. [7] found that stepwise recruitment applied during one lung ventilation had improved the oxygenation parameters, as when compared to 5 cmH₂O, PaO₂

Table 2. Between the two studied groups according to PaO₂/FIO₂ and PAO₂-PaO₂ gradient.

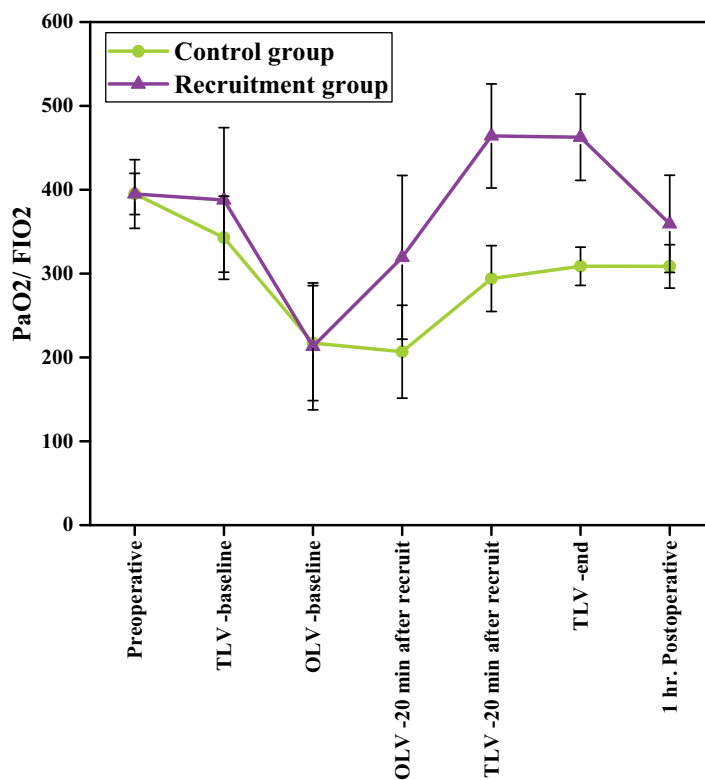
	Control group (n = 20)	p ₁	Recruitment group (n = 20)	p ₁	t	p
PaO₂/ FIO₂						
Preoperative	395 ± 24.6		394.9 ± 40.9		0.009	0.993
TLV-baseline	342.8 ± 49.6	<0.001*	387.9 ± 86.2	<0.001*	2.025	0.052
OLV-baseline	217.1 ± 68.5		213.2 ± 75.6		0.173	0.863
OLV-20 min after recruit	206.9 ± 55.4	0.494	319.4 ± 97.6	<0.001*	4.485*	<0.001*
TLV-20 min after recruit	294.1 ± 39.3	<0.001*	464.2 ± 62.1	<0.001*	10.356*	<0.001*
TLV-end	308.8 ± 22.9	<0.001*	462.7 ± 51.4	<0.001*	12.243*	<0.001*
1 h Postoperative	308.6 ± 25.9	0.001*	359.3 ± 57.9	<0.001*	3.573*	0.001*
PAO₂-PaO₂ gradient (mmHg)						
Preoperative	17.6 ± 5.3		15.6 ± 6.2		1.107	0.275
TLV-baseline	167.6 ± 29.3	0.003*	142.6 ± 51.9	<0.001*	1.877	0.070
OLV-baseline	275.2 ± 103.2		280.4 ± 105.5		0.159	0.874
OLV-20 min after recruit	287.6 ± 104.5	0.017*	192.7 ± 77	<0.001*	3.272*	0.002*
TLV-20 min after recruit	223.9 ± 67.8	0.403	97.40 ± 36.93	<0.001*	7.324*	<0.001*
TLV-end	205.5 ± 48.7	0.030*	97.9 ± 30.2	<0.001*	8.402*	<0.001*
1 h Postoperative	108.5 ± 20.02	<0.001*	88.4 ± 32.4	<0.001*	2.359*	0.024*

t: Student t-test.

p: p value comparing between the two studied groups.

p₁: p value for Post Hoc Test (Bonferroni) for ANOVA with repeated measures for comparing between OLV-baseline and each other periods.

*: Statistically significant at p ≤ 0.05.

**Figure 2.** Comparison between the two studied groups according to PaO₂/FIO₂.

was significantly greater with individualized PEEP at the end of one-lung ventilation. Also, Unzueta et al. [3] found that recruitment of both lungs before instituting OLV, improved arterial oxygenation in which there was a significant increase in PaO₂ after lung recruitment.

In contrast to our results, Roze et al. [11] found that lowering VT and raising PEEP with the same low plateau pressure (VT at 5 ml/kg and a PEEP level that kept a constant plateau pressure recorded before), decreased oxygenation when compared with higher VT and lower PEEP (VT at 8 ml/kg and a PEEP of 5 cm H₂O), during OLV and their

finding might be explained that the increased mean alveolar pressure in the dependent lung causes redistribution of pulmonary blood flow from overdistranded lung units in the dependent lung to the non-dependent lung, in contrast to the present study in which the individualized optimal PEEP was used.

As regards lung mechanics, in the present study, there was a significant increase in dynamic compliance in LR group after applying stepwise lung recruitment during OLV and TLV till the end of surgery. This could be explained that stepwise lung recruitment with pressure-controlled ventilation used a decelerating flow pattern

Table 3. Comparison between the two studied groups according to lung mechanics.

Lung mechanics	Control group (n = 20)	p ₁	Recruitment group (n = 20)	p ₁	t	p
PEEP (cmH₂O)						
TLV-baseline	5 ± 0		5 ± 0		–	–
OLV-baseline	5 ± 0	–	5 ± 0	–	–	–
OLV-20 min after recruit	5 ± 0	–	7.60 ± 1.54	0.001*	7.572*	<0.001*
TLV-20 min after recruit	5 ± 0	–	7.70 ± 1.63	0.001*	7.429*	<0.001*
TLV-end	5 ± 0	–	7.70 ± 1.63	0.001*	7.429*	<0.001*
Peak airway pressure (cmH₂O)						
TLV-baseline	20.30 ± 2.7		20.70 ± 3.1		0.438	0.664
OLV-baseline	23.80 ± 2.82	<0.001*	23.10 ± 2.10	<0.001*	0.890	0.379
OLV-20 min after recruit	24.7 ± 2.5	<0.001*	25.70 ± 3.1	<0.001*	1.192	0.241
TLV-20 min after recruit	23.2 ± 1.90	<0.001*	23.50 ± 3.80	<0.001*	0.368	0.716
TLV-end	23.80 ± 1.7	<0.001*	24.20 ± 3.91	<0.001*	0.420	0.678
Plateau pressure (cmH₂O)						
TLV-baseline	15.60 ± 2.84		15.1 ± 3.2		0.577	0.568
OLV-baseline	18.0 ± 1.84	<0.001*	16.90 ± 2.9	<0.001*	1.446	0.158
OLV-20 min after recruit	18.3 ± 1.94	<0.001*	18.6 ± 3.0	<0.001*	0.375	0.710
TLV-20 min after recruit	16.60 ± 2	0.811	16.8 ± 3.2	0.009*	0.178	0.860
TLV-end	16.9 ± 1.8	0.426	17.1 ± 3.10	0.007*	0.251	0.804
Mean airway pressure (cmH₂O)						
TLV-baseline	9.60 ± 0.9		9.60 ± 1.23		0.000	1.000
OLV-baseline	11.70 ± 1	<0.001*	11.8 ± 1.3	<0.001*	0.138	0.891
OLV-20 min after recruit	11.3 ± 1.41	0.003*	14.2 ± 1.90	<0.001*	5.483*	<0.001*
TLV-20 min after recruit	9.6 ± 1.01	1.000	12.3 ± 2.3	<0.001*	4.872*	<0.001*
TLV-end	9.50 ± 1.0	1.000	12.8 ± 2.3	<0.001*	5.863*	<0.001*
Dynamic compliance (mL/cmH₂O)						
TLV-baseline	57.7 ± 12.12		57.40 ± 14		0.048	0.962
OLV-baseline	31.40 ± 7.64		35.6 ± 9.34		1.538	0.132
OLV-20 min after recruit	30.0 ± 7.20	0.114	51.9 ± 10.61	<0.001*	7.620*	<0.001*
TLV-20 min after recruit	48.2 ± 8.73	<0.001*	74.10 ± 11	<0.001*	8.278*	<0.001*
TLV-end	48.50 ± 7.72	<0.001*	72.80 ± 9.83	<0.001*	8.695*	<0.001*

t: Student t-test.

p: p value comparing between the two studied groups.

p₁: p value for Post Hoc Test (Bonferroni) for ANOVA with repeated measures for comparing between OLV-baseline and each other periods.

*: Statistically significant at p ≤ 0.05.

Table 4. Comparison between the two studied groups according to TNF α (pg/mL).

TNF α (pg/mL)	Control group (n = 20)	p ₁	Recruitment group (n = 20)	p ₁	t	p
Preoperative						
Min.-Max.	4.01–6.02		4.01–5.97		0.311	0.757
Mean ± SD.	4.45 ± 0.61		4.50 ± 0.58			
1 h after surgery						
Min.-Max.	4.31–6.97	<0.001*	4.01–6.41	0.223	4.086*	<0.001*
Mean ± SD.	5.57 ± 0.74		4.64 ± 0.71			
24 h postoperative						
Min.-Max.	7.03–9.54	<0.001*	5.33–9.01	<0.001*	8.285*	<0.001*
Mean ± SD.	8.51 ± 0.77		6.43 ± 0.82			

t: Student t-test.

p: p value comparing between the two studied groups.

p₁: p value for Post Hoc Test (Bonferroni) for ANOVA with repeated measures for comparing between Preoperative and each other periods.

*: Statistically significant at p ≤ 0.05.

that resulted in a more homogeneous distribution of the tidal volume and improvement of the lung compliance due to recruitment of lung areas that were poorly ventilated and maintenance of individualized optimal PEEP which could keep the alveoli open and prevent alveolar recollapse and also minimizes overdistension.

In agreement with our results, Rausedo et al. [12] found that the application of an open lung ventilation strategy consisting of cycling recruitment followed by a decremental PEEP titration during OLV significantly improved lung compliance and compliance of the respiratory system. Also Ferrando et al. [7] found that recruitment applied during one lung ventilation had increased the static compliance significantly suggesting

a constant end-expiratory lung volume. Moreover, Miura et al. [13] found that respiratory compliance was significantly increased after recruitment during OLV.

In contrast to our results, Park et al. [14] found no differences in static or dynamic compliance between groups with and without preemptive alveolar recruitment strategy before OLV. And this could be attributed to stoppage of lung recruitment before OLV and application of standardized fixed PEEP of 5 cmH₂O during OLV with partial loss of end expiratory lung volume.

In the present study, there was a significant increase in TNF α in the control group 1 h after surgery and 24 h postoperative in relation to LR group. Lung recruitment in this study showed

a decreased degree of lung injury and this might be explained by reopening of atelectatic areas increasing the surface area for gas exchange and decreasing the mechanical stresses which causes ventilator induced lung injury. The recruiting pressure used during this study was 35 cmH₂O (PEEP 20 cmH₂O and inspiratory pressure of 15 cmH₂O) to decrease the incidence of lung injury and tidal over distension, as, high inspiratory pressure that exceed 40 cmH₂O during OLV, have been associated with the development of ALI [15]. Moreover, the use of stepwise recruitment maneuvers with gradual increase in peak pressure and PEEP was less detrimental to the alveolar capillary membrane, because the pressures were built up slowly [16], in contrast to the sustained inflation, which appeared to be more harmful [17].

In agreement with our results, Kim et al. [18] found that the level of TNF- α in the bronchoalveolar lavage (BAL) fluid of dependent lungs was significantly greater in the protective ventilation group than in the protective ventilation recruitment maneuver group when recruitment was applied 10 minutes after initiation of OLV. They demonstrated that recruitment and protective ventilation reduced inflammatory responses in the ventilated lung and serum compared to protective ventilation alone. Also, Schilling et al. [19] demonstrated that repetitive RMs during either OLV or two lung ventilation did not induce any significant pro-inflammatory responses. They concluded that it is OLV not lung recruitment that is detrimental and that repetitive alveolar recruitment maneuvers and bronchoscopic procedures did not increase the alveolar cytokine release.

In contrast to our results, Leite et al. [20] found that lung re-expansion of 30 cmH₂O during 30 seconds after OLV, caused cytokine release, protein extravasation and neutrophil infiltration into the alveolus. As elevated levels of interleukin (IL)-6, IL-1 and tumor necrosis factor-alpha in BAL fluid were detected, and elevated levels of IL-6 and IL-10 in serum were found. And this might be related to the use of sustained inflation maneuver not the stepwise maneuver.

5. Conclusion

Stepwise lung recruitment maneuver improved oxygenation parameters and lung mechanics during lung resection surgery and decreased the expression of lung injury biomarkers.

6. Limitations

The main limitation in the present study was small sample size and lack of patient follow-up to assess long-term effects of lung recruitment and its impact on hospital stay.

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ORCID

Mohamed Ibrahim Mohamed  <http://orcid.org/0000-0003-1790-8835>

Shahira Ahmed Yousef El-Metainy  <http://orcid.org/0000-0002-0654-5621>

Yasser Mohamed Osman  <http://orcid.org/0000-0002-9060-1058>

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