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Effect of individualized intraoperative lung recruitment maneuver on postoperative pulmonary complications in patients undergoing upper abdominal surgeries under general anesthesia

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ABSTRACT

Background: The concept of lung protective ventilation (LPV) during general anesthesia (GA) aims at minimizing lung injury and postoperative pulmonary complications (POPCs). Recruitment maneuver (RM) as a part of LPV may improve lung mechanics and oxygenation, but despite extensive research, definitive guidelines for the applications of intraoperative RMs have not been established yet.

Methods: This study was a prospective, single-blinded, randomized clinical trial. Sixty-six subjects undergoing non-laparoscopic upper abdominal surgeries under GA were randomly assigned into two equal groups. Control group (C) received tidal volume of 8 ml/kg predicted body weight (PBW) and positive end expiratory pressure (PEEP) of 5 cmH_2O without RM. Recruitment group (R) received tidal volume of 8 ml/kg PBW with stepwise RMs and individualized PEEP titration after each RM. Compliance, plateau pressure, driving pressure, SpO_2 and hemodynamics were monitored at each step of RM. POPCs, length of hospital stay and mortality were recorded postoperatively.

Results: There was a significant reduction in POPCs in (R) group than in (C) group ($P = 0.03$). Also, there was a significant increase in compliance before extubation in (R) group ($P = 0.001$). However, no significant difference was noted between both groups as regards mortality rate and length of hospital stay.

Conclusion: Individualized stepwise lung RM significantly decreases the incidence of POPCs when added to LPV in patients undergoing non-laparoscopic upper abdominal surgeries under GA.

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1. Introduction

Mechanical ventilation during general anesthesia (GA) is often considered as a safe maneuver. However, many studies in the past few years have linked mechanical ventilation with lung injury and postoperative pulmonary complications (POPCs) [1].

The term POPCs includes a variety of conditions that affect the respiratory system, usually during the first 7 postoperative days. Atelectasis, chest infection and respiratory failure are examples of POPCs [2].

The development of POPCs can lead to longer length of hospital stay, higher costs and rise in morbidity and mortality [3].

Recent researches illustrated that the principle of lung protective ventilation (LPV) can be applied to critically ill patients and also to patients at surgical theatre [4]. The aim of intraoperative LPV is to decrease lung injury, inflammatory response and POPCs [5].

The current data suggest that sufficient positive end expiratory pressure (PEEP) based on physiologic tidal volume (6–8 ml/kg predicted body weight (PBW)) is essential to keep the alveoli open. However, high levels of PEEP may affect hemodynamics and cause barotrauma, so optimal PEEP can be defined as the lowest possible PEEP which maintains the alveoli open [6].

There is a controversy over the use of intraoperative recruitment maneuver (RM) and the value of optimal PEEP. In this context, the term "individualized PEEP" has been recently used to identify the value of optimal PEEP based on patients' individual pulmonary mechanics as driving pressure and compliance [7].

The current study was built up to assess the effect of individualized RM on POPCs in patients undergoing upper abdominal surgeries under GA.

We hypothesize that stepwise lung RM added to LPV with individualized PEEP titration will result in a decrease in the incidence of POPCs compared to LPV without RM in patients undergoing non-laparoscopic upper abdominal surgeries under GA.

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Hence, the primary objective was to compare the incidence of POPCs in both groups, while the secondary objectives were to compare both groups regarding intraoperative pulmonary compliance, hospital length of stay and mortality rate.

2. Patients and methods

Following acceptance of the Committee of Ethics of Suez Canal Faculty of Medicine and getting informed written patient consent, this study was conducted in Suez Canal University hospitals between September 2019 and June 2022. Sixty-six subjects, aged ≥18 years, American Society of Anesthesiologists (ASA) physical status I or II undergoing non-laparoscopic upper abdominal surgeries with GA and mechanical ventilation were included in the study.

The criteria of exclusion were body mass index more than 35, history of lung disease, history of neuromuscular disease and hemodynamic instability (defined as a decrease in systolic blood pressure to ≤90 mmHg or a decrease in mean arterial pressure to ≤65 mm Hg).

The subjects were assigned randomly into two groups (33 patients each) using a web randomizer, and randomization sequence was concealed in opaque numbered envelopes that were opened on the day of surgery to show the group assignment.

Control group (C) received tidal volume of 8 ml/kg PBW with fixed PEEP 5 cmH_2O without RM, while recruitment (R) group was subjected to tidal volume of 8 ml/kg of PBW and stepwise lung RM with individualized PEEP titration. This study was single-blinded randomized controlled clinical trial.

At the operating room, an 18-gauge intravenous cannula was inserted. Standard monitoring of all patients was done by using GE AVANCE CS2 (GE Healthcare, USA) to show oxygen saturation (SpO_2%), non-invasive arterial blood pressure and electrocardiogram. End tidal CO_2 agent and NMT monitoring were connected after intubation.

Pre-induction SpO_2, heart rate and blood pressure were recorded as baseline values. All patients were pre-oxygenated with oxygen in air (FiO_2) 0.8 to attain a fraction of expired oxygen ($FetO_2$) greater than 0.6.

Induction of anesthesia was achieved by 2 µg/kg fentanyl and 2–3 mg/kg propofol. Endotracheal intubation was aided with 0.15 mg/kg cisatracurium. Maintenance of anesthesia was done with 1.2 to 1.5 MAC isoflurane and was changed to preserve hemodynamics within 20% of preoperative values. All subjects received 1 g paracetamol IV and if required 1 ug/kg fentanyl to keep hemodynamics within target.

Initial ventilator settings for all patients were as follows: tidal volume of 8 ml/kg of PBW, respiratory rate of 12 breaths/min and was adjusted to keep normocapnia ($EtCO_2$ 35–45 mmHg), FiO_2 of 0.4 fresh gas flow 1 liter, PEEP of 5 cmH_2O, inspiratory:expiratory (I:E) ratio of 1:2 in pressure-controlled volume guaranteed ventilation (PCV-VG) mode, utilizing GE, Avance anesthesia station. We switched to volume-controlled ventilation mode for 3–5 breaths before measuring, plateau pressure (measured by inserting an end inspiratory pause of 1 second), pulmonary compliance (tidal volume/plateau pressure – PEEP) and driving pressure (difference between plateau pressure and PEEP) that were recorded as pre-recruitment, post-recruitment and before extubation.

Lung recruitment was done in (R) group after induction of anesthesia, using stepwise approach by increasing PEEP in increments of 2 cmH_2O every 5 breaths as long as compliance increases.

When compliance started to decrease, PEEP was decreased in 2 cmH_2O decrements every 5 breaths until sudden drop in compliance happens, and at this point RM was stopped and PEEP was adjusted to the point 2 cmH_2O above the level at which sudden drop in compliance occurs (Individualized PEEP). Plateau pressure, driving pressure, pulmonary compliance, SpO_2, HR and BP were monitored and recorded at each step of RM. If hemodynamic instability (defined as a decrease in systolic blood pressure to ≤90 mmHg or a decrease in mean arterial pressure to ≤65 mm Hg) was observed at any step, RM would have been immediately held and a fluid challenge and/or vasopressor agent (Ephedrine 5–10 mg IV) was administered to maintain hemodynamic stability.

RM was repeated in (R) group every 30 minutes till the end of surgery and after any disconnection from the mechanical ventilation or repositioning of the patient.

Regarding IV fluids, Ringer acetate was infused in both groups in a rate of 10 ml/kg/hour. Further solutions were given when needed.

At the end of surgical procedure, all anesthetic agents were stopped and 80% oxygen in air ventilation was given.

The residual effect of cisatracurium was reversed if needed according to neuromuscular monitoring using neostigmine (0.05 mg/kg) and atropine (0.01 mg/kg) to target TOF% of 0.9. Patients were extubated after restoring consciousness and then shifted to the post-anesthesia care unit (PACU) for follow-up where vital signs were recorded and ABG sample was obtained.

After fulfilling the criteria of discharge from PACU (modified Aldrete score = 10), patients were moved to the ward and chest X-ray was done during the first 6 hours postoperatively.

POPCs as defined and diagnosed by European Perioperative Clinical Outcome (EPCO) [8] include the occurrence of one or more of the following: respiratory infection, pleural effusion, atelectasis, bronchospasm, aspiration, pneumothorax and respiratory failure. POPCs were recorded during the first 7 postoperative days (Table 1) [8].

Table 1. Postoperative pulmonary complication as defined by EPCO[8].

Complication	Definition
Respiratory infection	Patient has received antibiotics for a suspected respiratory infection and met one or more of the following criteria: new or changed sputum, new or changed lung opacities, fever, white blood cell count >12000
Respiratory failure	Postoperative PaO_2 <8 kPa (60 mmHg) on room air, an SpO_2 <90% and requiring oxygen therapy
Atelectasis	Chest radiograph demonstrating blunting of the costophrenic angle, loss of sharp silhouette of the ipsilateral hemidiaphragm in upright position, evidence of displacement of adjacent anatomical structures or (in supine position) a hazy opacity in one hemithorax with preserved vascular shadows
Pleural effusion	Lung opacification with a shift of the mediastinum, hilum or hemidiaphragm toward the affected area and compensatory over-inflation in the adjacent non-atelectatic lung
Pneumothorax	Air in the pleural space with no vascular bed surrounding the visceral pleura
Bronchospasm	Newly detected expiratory wheezing treated with bronchodilators
Aspiration pneumonitis	Acute lung injury after the inhalation of regurgitated gastric contents

The following items were recorded and used for data analysis in all groups: name and type of surgery (elective or emergent), duration of surgery, Ariscat score [9], compliance and driving pressure recorded immediately after induction, immediately before and after each recruitment and immediately before extubation (for statistical analysis, we compared compliance in control and RM groups immediately after induction (before starting RM|) and before extubation (after finishing all RMs) to assess the effect of RM on lung mechanics), BP, HR and SpO_2 (immediately pre-anesthesia at preoperative holding area, immediately after induction, after each recruitment, immediately before extubation, immediately after anesthesia at PACU), PaO_2/FiO_2 ratio immediately after surgery at PACU, incidence, type and number of POPCs, non-pulmonary complications, length of hospital stay and mortality rate.

3. Statistical analysis

G. Power software was used for sample size calculation. Sixty-six patients were included to get 10% difference in POPCs after RM where alpha error was 5% and power was 80% [10].

Data analysis was done by IBM SPSS software version 20.0. Quantitative data were represented using mean, standard deviation and range. Qualitative data were represented with percentage and number. Significance of the results was considered at *P* value ≤0.05.

Student independent sample and paired t-test were used for quantitative and normally distributed variables. Chi-square test was used for the analysis of categorical data.

4. Results

Seventy-four subjects were evaluated for being eligible to be included in this study; eight subjects were excluded because they were not fulfilling the inclusion criteria. Sixty-six subjects were enrolled in the study. Consequently, statistical analysis was performed on 66 subjects (33 subjects in each group) as shown in Figure 1.

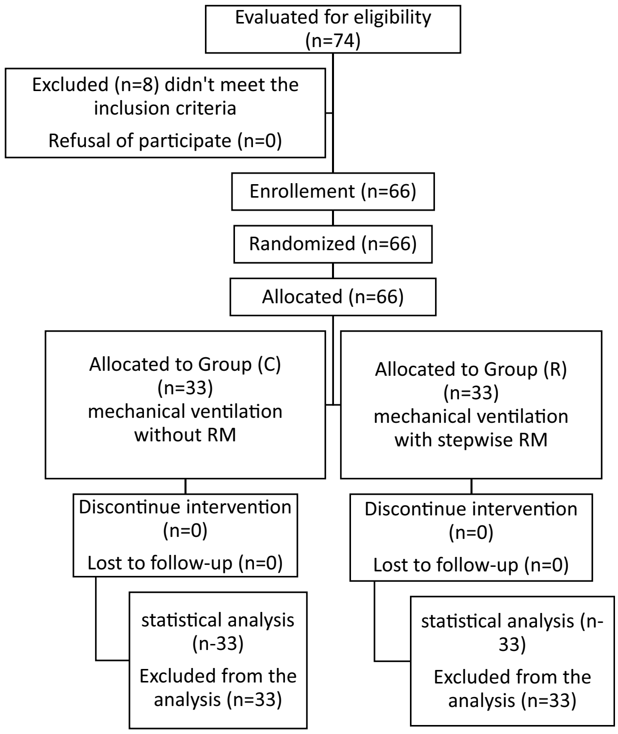

Figure 1. CONSORT flow chart of the patients.

The patients' characteristics were considered to be comparable in both groups (Table 2).

The incidence of POPCs was significantly lower in the recruitment group when compared to the control group. Ten patients developed POPCs in control group (30.3%) compared to only three patients in the recruitment group (9.1%) (p value = 0.03) (Figure 2).

The length of hospital stay showed no significant difference between (R) group and (C) group (5.5 ± 3.1 vs 6.8 ± 4.2 days: $P = 0.18$). Moreover, there was no significant difference regarding the mortality rate in (R) group and (C) group (1 vs 0: *P* value 1).

Baseline lung compliance was found to be comparable between both groups. Analysis of compliance before extubation showed a significant rise in lung compliance in the (R) group (P < 0.001) (Figure 3).

In (R) group, mean PEEP after RM was 6.82 cmH_2O (SD ± 1.29) and that was significantly higher than fixed PEEP of 5 cmH_2O in (C) group (*P* value 0.001).

Table 2. Patients characteristics.

	Control group (*n* = 33)		Recruitment group (*n* = 33)		
	No.	%	No.	%	p
Sex					
Male	14	42.4	17	51.5	0.459
Female	19	57.6	16	48.5	(NS)
Age (years)					0.345
Min. – Max.	21.0–60.0		23.0–59.0		(NS)
Mean ± SD.	45.40 ± 11.38		47.91 ± 10.04		
BMI (kg/m2)					
Min. – Max.	18.0–33.0		20.0–34.0		0.146 (NS)
Mean ± SD.	26.97 ± 3.41		28.16 ± 3.22		
Duration of surgery (minutes)	60.0–360.0		75.0–360.0		0.466 (NS)
Min. – Max.	136.97 ± 64.12		136.36 ± 49.97		
Mean ± SD.					
ASA physical status					
I	18	54.5	14	42.4	0.325 (NS)
II	15	45.5	19	57.6	
Ariscat score(9)	6	18.2	7	21.2	0.804 (NS)
Low	16	48.5	14	42.4	
Intermediate	11	33.3	12	36.4	
High					

Note: (NS): Statistically non-significant.
Sex, ASA physical status and Ariscat score are expressed as number (percent%).
BMI, duration of surgery and age are expressed as mean ± SD.

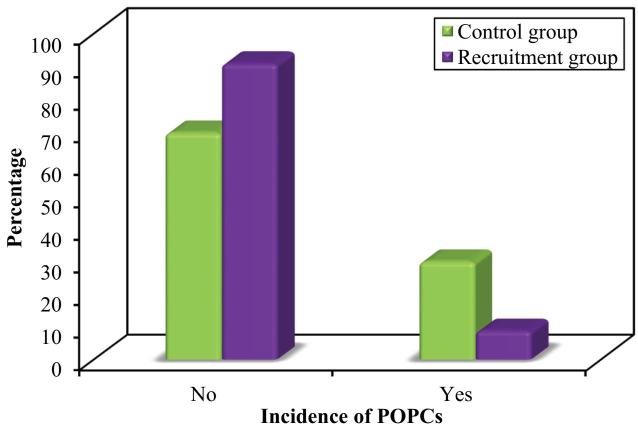

Figure 2. Incidence of POPCs in both groups. *: Statistically significant at $p \le 0.05$.

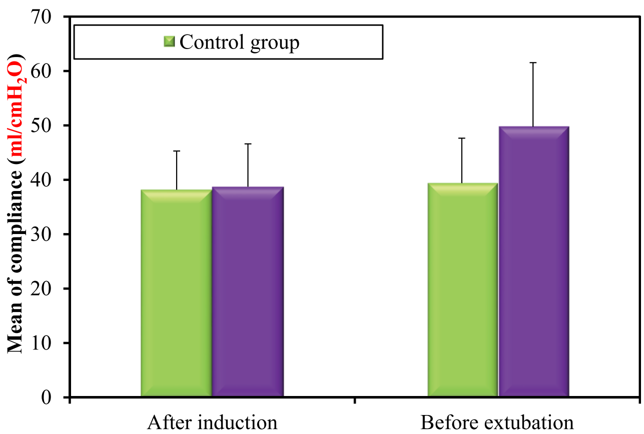

Figure 3. Lung compliance in the two groups. (NS): Statistically non-significant difference. *: Statistically significant at $p \le 0.05$. Error bars represent the standard deviation.

Driving pressure before extubation was gsignificantly reduced in (R) group ($P = 0.006$) (Table 3).

SpO_2 before extubation showed a significant rise in (R) group (P value 0.025). Post-anesthesia SpO_2 was significantly increased in (R) group (P value 0.013).

Table 3. Driving pressure in the two groups.

Driving pressure (cmH_2O)	Control group (n = 33)	Recruitment group (n = 33)	P_1
After induction	8.0–16.0	9.0–16.0	0.611 (NS)
Min. – Max.	12.06 ± 1.77	11.85 ± 1.60	
Mean ± SD.			
Before extubation			
Min. – Max.	8.0–17.0	8.0–16.0	0.006*
Mean ± SD.	11.73 ± 2.40	10.25 ± 1.85	
P_2	0.190 (NS)	<0.001*	

Note: P_1: p value for comparing driving pressure between the studied groups.
P_2: p value for comparing driving pressure after induction and before extubation within each group. *: Statistically significant at $p \le 0.05$. (NS): Statistically non-significant difference. Data are expressed as Mean ± SD.

Also, Postoperative PaO_2/FiO_2 ratio was significantly higher in (R) group ($P = 0.02$).

Hemodynamic parameters (heart rate and mean arterial blood pressure) were found to be comparable in both groups, and there was no recorded hemodynamic comprise during RM.

5. Discussion

GA with mechanical ventilation is widely performed in surgical operations. However, adverse respiratory effects as decrease of FRC and development of atelectasis begin shortly after the patient loses consciousness [11].

Abdominal surgeries increase the risk for POPCs. It is worth mentioning that upper abdominal surgeries increase the risk of POPCs up to 15 times when compared to lower abdominal surgeries [12].

Health care costs, length of hospital stay, morbidity and mortality are all increased by the development of POPCs. Anesthesiologists should become mindful of high-risk patients and have a plan for managing them [13].

The current study evaluated the effect of stepwise RM followed by individualized PEEP titration compared to LPV without RM on POPCs in patients performing upper abdominal surgeries under GA.

We hypothesized that effective RM should be individualized according to each patient's response and combined with the setting of appropriate PEEP. Therefore, in this study, we used stepwise RM followed by the setting of individualized PEEP using PCV-VG mode of ventilation to allow for continuous delivery of physiological tidal volume with the lowest appropriate peep needed to keep lungs open.

The key finding of the current study was that the incidence of POPCs was significantly lower in the stepwise recruitment group than in control group.

Cui et al. [14] carried out a meta-analysis in 2019 to demonstrate the impact of RM on POPCs in patients undergoing GA and found that the RM with protective ventilation strategy may lower the development of POPCs and improve oxygenation.

Furthermore, Halawa et al. [15] in 2021 reported that stepwise RM was associated with significant decrease in POPCs during liver transplant surgeries.

In contrast, the PROVHILO study [16] included 900 patients undergoing open abdominal surgery and found no difference in POPCs in both RM and non-RM groups. In this study, a fixed PEEP of 12 cmH_2O was applied during RM with an incremental rise in tidal volume in contrast to our study which allowed for individual variations in the PEEP requirements.

Our study showed no significant difference between both groups as regards hospital stay and mortality rate.

Halawa et al. [15] and PROVHILO study reported similar findings as regards hospital stay and mortality rate.

Our study showed a significant increase in compliance before extubation in the (R) group.

Li et al. [6] in 2021 in a meta-analysis on the influence of individualized PEEP with RM on mechanical ventilation during abdominal surgery found that the compliance was increased significantly in recruitment group.

Halawa et al. [15] also found that compliance increased significantly in recruitment group versus control group.

On the other hand, Singh et al. [17] performed a study of the value of intraoperative PEEP and RM on pulmonary functions during laparotomy and found no significant difference in compliance in RM and non-RM groups. In this study, the RM used was a sustained manual inflation of the lungs to a peak pressure of 30 cmH_2O in contrast to our study which allowed for individual variations in the PEEP requirements by using stepwise RM.

An interesting finding in the current study showed that mean PEEP after RM was significantly higher in (R) group than fixed PEEP of 5 cmH_2O in (C) group.

Halawa et al. [15] also found that PEEP after RM increased significantly in (R) group versus (C) group.

Also, this study showed a statistically significant reduction in driving pressure before extubation in the (R) group.

This finding coincided with the results of Li et al. [6] who found that driving pressure was decreased significantly in recruitment with individualized PEEP group.

Our study showed a significant increase in postoperative PaO_2/FiO_2 in the (R) group. Also, it showed a significant rise in postoperative SpO_2 in the (R) group.

Sayed El Hefny et al. [18] concluded that stepwise RM increased oxygenation and pulmonary mechanics in thoracic surgery and decreased the biomarkers of lung injury. In addition, Li et al. [6] found that PaO_2/FiO_2 ratio was increased significantly in recruitment group. Halawa et al. [15] have found same results.

The key limitation in the current study was smaller sample size, so we recommend larger and multi-center studies to verify the results of this study.

6. Conclusion

Our study concluded that individualized stepwise lung RM significantly decreases the incidence of POPCs when added to protective lung ventilation in patients undergoing non-laparoscopic upper abdominal surgeries under GA.

Disclosure statement

No potential conflict of interest was reported by the author (s).

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