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Intraoperative Lung-Protective Ventilation Strategy for Patients Undergoing Open Abdominal Surgeries in Trendelenburg Position

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Research Article

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Abstract

Introduction: Extreme steep Trendelenburg position (T-position) of 25–40° could contribute to atelectasis formation, elevate mechanical stress in pulmonary parenchyma, triggering significant perioperative pulmonary dysfunction. Intraoperative lung-protective mechanical ventilation (LPV) has been reportedly able to attenuate ventilator-induced lung injuries (VILI) by employing a low tidal volume (V_t), an appropriate level of PEEP, and recruitment maneuvers (RMs).

Aim: To compare intraoperative and postoperative changes in PaO_2/FiO_2 ratio, differences between the two groups regarding PaO_2 and (A-aO_2); intraoperative Cdyn (Dynamic compliance) and Cstat (Static compliance), and the incidence of atelectasis detected on chest x-ray on the first postoperative day.

Materials and Methods: This was a prospective, randomised comparative study conducted in a group of 60 patients of ASA I,II and III with age 18-65 years of either gender planned to undergo elective open abdominal surgeries in Trendelenburg position between April 2022 to September 2022. The study population was divided randomly into 2 groups. Group A received Conventional ventilation (CV) - tidal volume 10 ml kg^{-1} IBW, 0.4 FiO_2 without PEEP and Recruitment Manoeuvre. Group B received Lung protective ventilation (LPV) - tidal volume of 7 ml kg^{-1} IBW, 0.4 FiO_2, recruited alveoli by applying a stepwise increase in PEEP (from 4 to 10 cm H_2O for 3 breaths, 10 to 15 cm H_2O for 3 breaths, and 15 to 20 cm H_2O for 10 breaths), 30min after intubation, 30min post Abdominal retraction, 60min before extubation and at extubation with maximum PIP (Peak Inspiratory Pressure) of 50 cm H_2O.

Results: Our study revealed that, the intraoperative PaO_2/FiO_2 ratio and PaO_2 were significantly higher in LPV group than those in CV group ($p < 0.05$). The intraoperative (A-a)O_2 was lower in the LPV group than that in CV group, while the $PaCO_2$ and $EtCO_2$ during surgery were comparable in both groups.

Hemodynamic data was comparable in both the groups at all points of time. There was no difference in incidence of atelectasis as seen by chest X-ray between the two groups after surgery. Length of stay in postoperative care unit was also comparable in both groups.

Conclusion: In non-obese patients undergoing open abdominal surgery in Trendelenburg position, lung-protective mechanical ventilation when performed with low tidal volumes (7ml/kg) combined with PEEP and intermittent recruitment maneuver improves PaO_2/FiO_2 ratio without causing significant hemodynamic instability.

Keywords: Lung Protective Ventilation(LPV); PEEP; Compliance Remove Lung

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Introduction

Extreme steep Trendelenburg position (T-position) of 25–40 degrees could contribute to atelectasis formation, particularly in dependent regions and elevate mechanical stress in pulmonary parenchyma, triggering significant perioperative pulmonary dysfunction [1]. Administration of general anesthesia further decreases the end-expiratory lung volume (EELV) forming atelectasis, and leads to a deterioration in respiratory mechanics and gas exchange [2]. Ventilation strategy employing high tidal volumes could overdistend normal lungs, thereby activating a local inflammatory reaction. Furthermore, zero-positive end-expiratory pressure or low levels of positive end-expiratory pressure (PEEP) could induce repetitive collapse and reopening of the alveoli, which ultimately result in an inflammatory injury [3].

Conventional mechanical ventilation refers to the use of a positive pressure ventilator to deliver tidal breaths with conventional target/cycling parameters via an endotracheal tube. Using conventional trigger, target, and cycling mechanisms, the goal is to generate or support a tidal breath that will help maintain appropriate partial pressures of oxygen (O_2) and carbon dioxide (CO_2) in the arterial blood. The ventilator may be used to completely or partially perform the work of breathing [4].

In recent years, intraoperative lung-protective mechanical ventilation (LPV) has been reportedly able to attenuate ventilator-induced lung injuries (VILI) [5] by employing a low tidal volume (V_t), an appropriate level of PEEP, and recruitment maneuvers (RMs). The goals of these interventions are to minimize alveolar overdistention, to prevent repeated collapse and reopening of alveoli and to reduce atelectasis.

Lung Protective Ventilation studies were done in Laparoscopic and open Abdominal surgeries. Some of these studies revealed improvement of intraoperative lung oxygenation and reduced postoperative pulmonary complications but they did not study pulmonary mechanics and postoperative oxygenation. In this study our aim was to compare Conventional Ventilation (CV) and Lung Protective Ventilation (LPV) both intra and postoperatively and improve lung function in patients undergoing open Abdominal surgeries in Trendelenburg position.

Hypothesis

Lung protective ventilation will improve intraoperative lung oxygenation (P/F ratio, Pao_2) function, pulmonary mechanics and prevent early postoperative Atelectasis.

Aim of the Study

Primary Objective

To compare intraoperative and postoperative changes in P/F ratio (PaO_2/FiO_2).

Secondary Objective

To observe the differences between the two groups regarding PaO_2, A-aO_2; intraoperative dynamic compliance (C_{dyn}) and static compliance (C_{stat}), and the incidence of atelectasis detected on chest x-ray on the 1st postoperative day.

Methodology

Study Design

A prospective, randomized, comparative study was conducted after institutional ethics committee approval with Review letter No.EC/NIMS/2888/2021, 58th ESGS No. 1262/2021.

Study Site

The study was conducted at Surgical Oncology OT, Nizam's Institute of Medical Sciences, Panjagutta, Hyderabad, Telangana.

Study Period

This study was conducted between April 2022 to September 2022.

Study Population

This study recruited adult patients between the age of 18 to 65 years, who were ASA I,II,III of both gender undergoing open abdominal surgery in Trendelenburg position.

Sample Size

The sample size was calculated in accordance with the formula: $n = (2 \times C)/\delta^2 + 1$ with $\delta = |\mu_1-\mu_2|/\sigma$, where n is the sample size in each group, μ_1 = mean of PaO_2/FiO_2 ratio in LPV group, μ_2 = mean of PaO_2/FiO_2 ratio in CV group, σ is the common standard deviation and c = 7.9 for 80% power. The primary outcomes in the study of Xin Pi (2015) – (B5) showed that the PaO_2/FiO_2 ratio after 2 h of ventilation in the two groups was 382.21 ± 88.03 and 450.10 ± 70.29 respectively. Replacing μ_1 = 382.21, μ_2 = 450.10, σ = 88.03 in the formula, n was equal to 27.5 for each group. This represented that the minimum sample size for each group was at least 28 patients.

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To account for dropouts a sample size of 35 patients in each group is decided.

Selection of Study Participants

Inclusion Criteria

- Age group 18 to 65 years
- Either male or female
- ASA I, II, III
- Duration of surgery greater than 2 hours

Exclusion Criteria

- Refusal to participate in the study
- Preexisting significant cardiac or pulmonary comorbidities (heart failure, intractable shock, Chronic obstructive pulmonary disease, Asthma, pulmonary infection, bronchiectasis, pulmonary metastases)
- Pre-existing abnormalities on chest X-ray or spirometry.
- History of neuromuscular disease
- Liver cirrhosis (Child B or C), or chronic renal failure with hemodialysis and then
- Need to continue prolonged mechanical ventilation after surgery.

Method

After obtaining approval from the institutional ethics committee, informed and written consent from the patients, this observational study was carried over a period of 6 months on patients of ASA grade I,II and III, aged 18 to 65 years. The study was done in patients electively posted for open major abdominal surgeries in Trendelenburg position. Patients were randomly categorized into 2 groups based on computer generated allocation method with sample size of 60. In PAC, Solid food was allowed until 8 hours and clear fluids up to 2 hrs before surgery. Premedication was given with Tab. Ranitidine 150mg and Tab.Alprazolam 0.25mg on the night before surgery. After shifting the patient to the OT, under strict aseptic precautions large bore IV cannulas were placed. In the OT standard protocol for monitoring and placement of invasive line (Arterial) was followed. Baseline HR, SBP, DBP, MAP, and SpO_2, and ABG parameters (FiO_2, PaO_2, $PaCO_2$) were noted. After premedication with Fentanyl 2mcg/kg, Propofol 1.5-2 mg/kg was used for induction. Rocuronium/ Atracurium was used for achieving muscle relaxation. Mask ventilation was continued for 3 minutes using Sevoflurane in an O_2 and Air (50/50) mixture. Under direct Laryngoscope the patients were intubated with appropriate size oral ET tube. The ventilator was set accordingly

Group A

Conventional Group (CV): Tidal volume was set at 10ml/kg IBW, with 0.4 FiO_2.

Group B

Lung Protective Ventilation (LPV): Tidal volume of 7ml/kg IBW with 0.4 FiO_2; alveoli were recruited by applying a stepwise increase in PEEP (from 4 to 10 cm H_2O for 3 breaths, 10 to 15 cmH_2O for 3 breaths, and 15-20 cm H_2O for 3 breaths) with maximum PIP (Peak Inspiratory Pressure) of 50cm H_2O. The recruitment manoeuvres were performed 30min post intubation, 30min post abdominal retraction, 60min before extubation and at extubation.

HR, BP, SpO_2, and $EtCO_2$ were noted at baseline, after intubation, after Abdominal retraction and at the end of surgery. ABG values PaO_2, $PaCO_2$, A-aO_2 difference, and Pao_2/FiO_2 ratio were noted before induction, 30min after intubation, after abdominal retraction, before extubation, 1 hour post-op and 24 hours post-op. Respiratory dynamics like PIP, C_{dyn} (dynamic compliance), Vte, Plateau pressure, PEEP, C_{stat} (static compliance) were noted at 30 min post-intubation, 30min post abdominal retraction, 60min before extubation, at extubation [6].

Data Recording and Statistical Analysis

All the data were collected, tabulated and checked for correctness and consistency. Statistical analysis was carried out using SPSS 22.0 and R environment ver.3.2.2. Microsoft word and Excel have been used to generate graphs, tables etc. Statistical analysis was performed using SPSS software version 20.0 (IBM, USA) on an intention-totreat basis. Continuous variables were compared applying either Student's t-test or the MannWhitney U test, and consequently reported as mean ± SD or median and interquartile range (25–75%) as appropriate. Comparisons of normally distributed variables were performed with one-way ANOVA. As for categorical variables, the $\chi 2$test was employed for comparison and the Fisher exact test was used for small frequencies. All the tests will be two-tailed, and statistical significance accepted at $p < 0.05$.

70 patients were screened for recruitment for the study based on inclusion and exclusion criteria. They were randomized into the Group Conventional Ventilation - CV (control) and Group LPV-Lung Protective Ventilation (study group). 1 patient in Group CV and 2 patients in group LPV were excluded after initial recruitment. The study was conducted on 34 controls and 33 study patients. Postoperative data was available for final analysis in 30 patients in Group CV and 31 patients in Group LPV (Figure 1).

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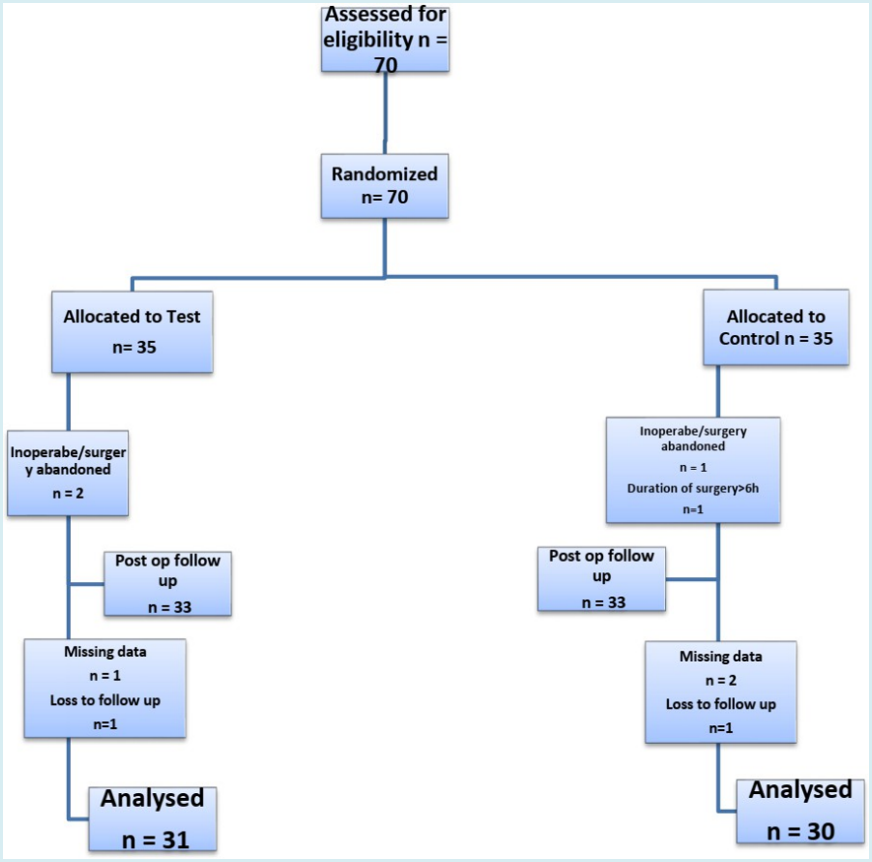


Figure 1: Consort Flow Diagram.

The demographic data was comparable between the two groups. The mean age of the patients in group C V was 44.8±16 and in group LPV was 46.9±10.0. The mean BMI of the patients in group CV was 20.77±6.8 and in group LPV was 21.4±6.4. The M: F ratio was comparable in both groups. In both groups comorbidities hypertension, diabetes and thyroid diseases were comparable (Table 1) (Figure 2).

Parameter		GROUP CV	GROUP LPV	p Value
		MEAN± SD		
Age (yrs)		44.8±16	46.9±10.0	0.32
BMI (kg/m^2)		20.77±6.8	21.4±6.4.	0.26
BHT (seconds)		25.2±6.37	27.01±5.9	0.42
Sex(M:F)		20:10	22:09	0.11
comorbidities	HTN	3(10%)	5(16.1%)	0.07
	DM	5(16.6%)	6(19.4%)	0.09
	THYROID	1(3.33)	1(3.22%)	0.18

Table 1: Comparison of Demographic Data.

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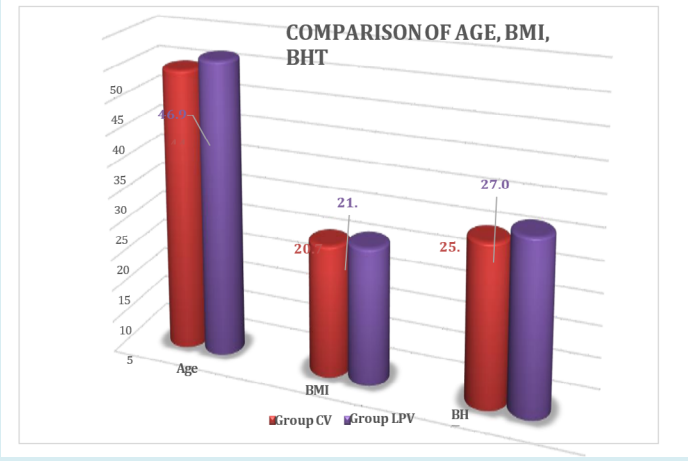


Figure 2: comparison of Age, BMI and BHT.

Data are shown as mean ± SD or median [interquartile range] as appropriate Figure 2 Comparison Of AGE, BMI, BHT

Comparision of Duration of Surgery, Intraoperative Fluids, Blood Loss and Inotrope Requirement

The duration of anesthesia, duration of surgery, intraoperative fluids and blood loss were comparable in group CV and group LPV. The number of patients who required inotropic support were also comparable in both groups (Table 2) (Figures 3 & 4).

Parameter	Group CV	Group LPV	p Value
	MEAN± SD		
Duration of surgery (hrs)	3.9±1.3	3.76±1.2	0.88
Fluids (ml)	1785.8±448.5	1770±500.6	0.87
Blood loss (ml)	274.2±170.6	260±200.4	0.89
Inotrope n(%)	2(6.6%)	3(9.7%)	0.12

Table 2: Comparison of Duration of Surgery, Intraoperative Fluid, Inotrope Requirement and Blood Loss.

Data are shown as mean ± SD or median [interquartile range] as appropriate

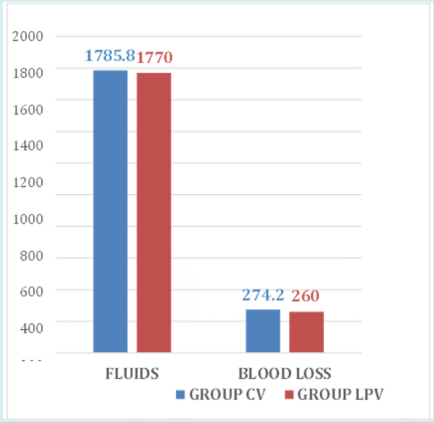


Figure 3: Comparison of Fluids and Blood Loss.

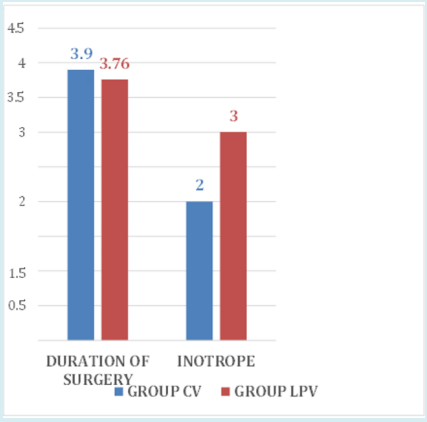


Figure 4: Comparison of Duration of Surgery & Inotrope.

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Comparison of Arterial Blood Gas Analysis

There were no significant differences regarding blood gas between the two groups at base line. The pH was comparable between the 2 groups at all time points intraoperatively as well as in postoperative period. The intraoperative PaO_2 and P/F ratio in LPV group were significantly higher than those in CV group ($p < 0.05$). The intraoperative A-aO_2 in LPV group was clearly lower than that in CV group, while the $PaCO_2$ and $EtCO_2$ during surgery was comparable in both groups.

The pH values were comparable between the groups at all times (Table 3) (Figure 5).

pH	GROUP CV	GROUP LPV	p value
Baseline	7.44±0.02	7.42 ±0.04	0.08
30min after intubation	7.32±0.03	7.33±0.04	0.82
30 min after abdominal retraction	7.24±0.77	7.31±0.07	0.42
1hr before extubation	7.42±0.06	7.41±0.00	0.35
1hr post op	7.34±0.02	7.35±0.06	0.81
24hr post op	7.41±0.04	7.39±0.03	0.83

Table 3: Comparison of Arterial Blood Gas pH.

Data are shown as mean ± SD or median [interquartile range] as appropriate

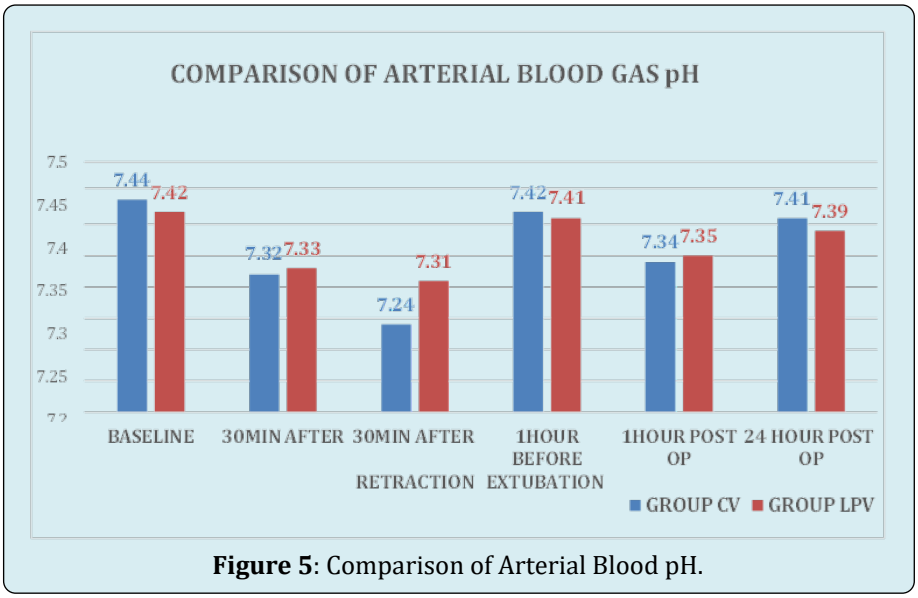


Figure 5: Comparison of Arterial Blood pH.

Data are shown as mean ± SD or median [interquartile range] as appropriate

The intraoperative paO_2 in LPV group were significantly higher than those in CV group ($p < 0.05$) (Table 4) (Figure 6).

paO_2	GROUP CV	GROUP LPV	p value
Baseline	86 [78–91]	84 [79–95]	0.09
30min after intubation	86 [80–90]	88[82–94]	0.84
30 min after abdominal retraction	186 [188–200]	210 [190–222]	0.002*
1hr before extubation	180 [175–210]	214 [189–228]	0.001*
1hr post op	100[90–124]	122[101–184]	0.01*
24hr post op	90 [80–143]	94 [87–136]	0.83

Table 4: Comparison of Intraoperative paO_2.

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Data are shown as mean ± SD or median [interquartile range] as appropriate; * p value <0.05

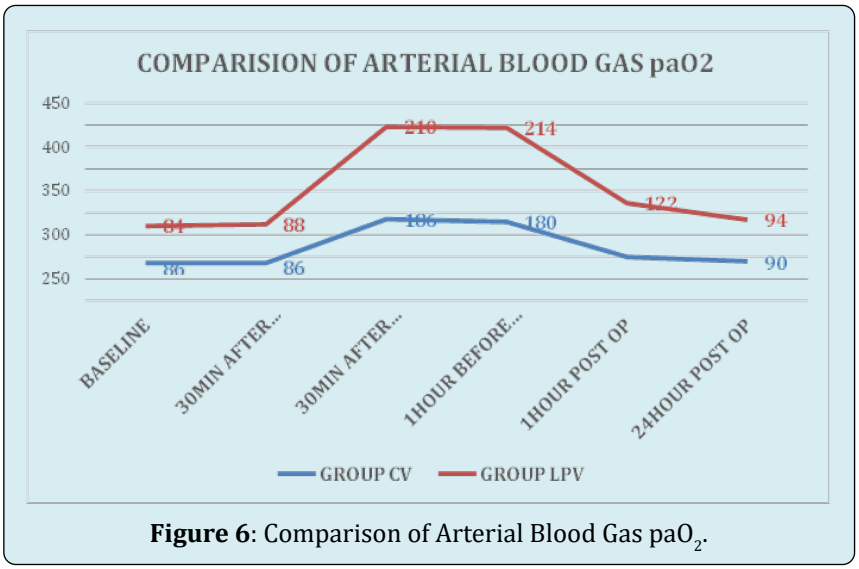


Figure 6: Comparison of Arterial Blood Gas paO_2.

The intraoperative $A\text{-}aO_2$ in LPV group was clearly lower than that in CV group (Table 5) (Figure 7).

Time intervals	Group CV	Group LPV	p value
Baseline	19 ± 6 11–33	19 ± 7 10–31	0.44
After intubation	20 ± 7 10–34	20 ± 6 9–33	0.66
After abdominal retraction/laparotomy	54 ± 38 18–110	22 ± 11 7–79	0.03*
Before extubation	89.1 ±40.0	67.7±54	0.001*
1hr post op	147.9±59	134.2±74	0.006*
24hr post op	57 ± 28 10–105	47 ± 34 10–110	0.51

Table 5: Comparison of $(A\text{-}aO_2)$ Difference.

Data are shown as mean ± SD or median [interquartile range] as appropriate; * p value <0.05

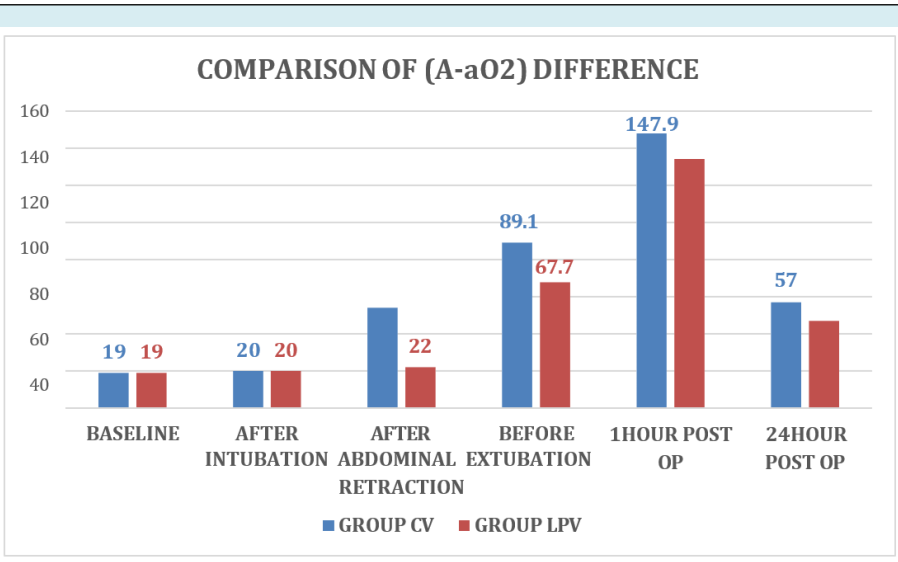


Figure 7: Comparison of $(A\text{-}aO_2)$ Difference.

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P/F (PaO_2/FiO_2 ratio) in LPV group were significantly higher than those in CV group ($p < 0.05$) (Table 6) (Figure 8).

Time intervals	Group CV		Group LPV		p value
Baseline	425	330–473	400	316–466	0.44
After intubation	405	330–473	396	330–473	0.6
After abdominal retraction/laparotomy	484	[388–505]	514	[490–572]	0.002*
Before extubation	479	[381–520]	512	[488–567]	0.001*
1hr post op	362.3	[351–500]	417	[377–457]	0.006*
24hr post op	328	[275–433]	337	[300–483]	0.41

Table 6: Comparison of PaO_2/FiO_2 Ratio.

Data are shown as median [interquartile range] as appropriate; * p value <0.05.

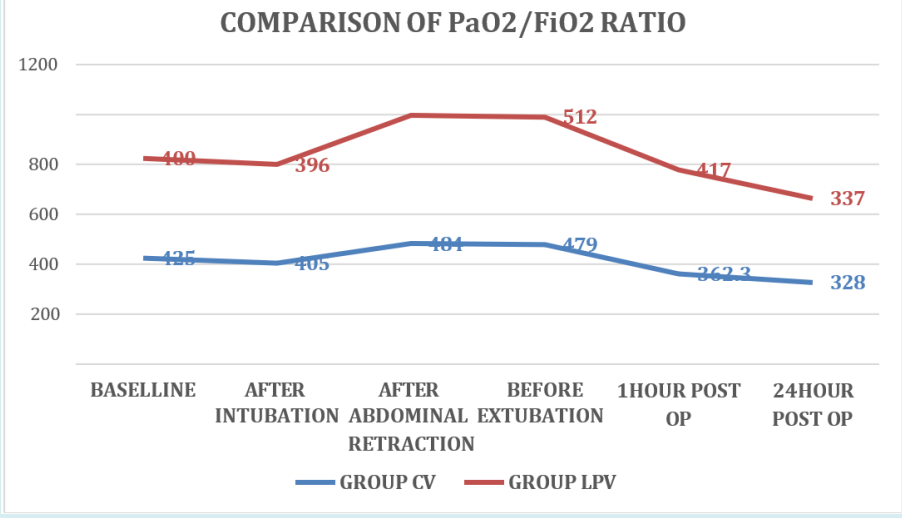


Figure 8: Comparison of PaO_2/FiO_2 Ratio.

The PaCO2 levels during the surgery was comparable in both groups (Table 7) (Figure 9).

$paCO_2$	GROUP CV	GROUP LPV	p value
Baseline	31.6±10.7	32.5±9.7	0.39
30min after intubation	33.0±3.8	35.9±3.9	0.56
30 min after abdominal retraction	35.4±4.7	34.3±4.2	0.98
1hr before extubation	34.4±3.3	33.7±4.0	0.47
1hr post op	34.7±4.2	33.9±4.3	0.29
24hr post op	34.9±5.0	36.6±5.0	0.46

Table 7: Comparison of $PaCO_2$ levels

Data are shown as mean ± SD or median [interquartile range] as appropriate.

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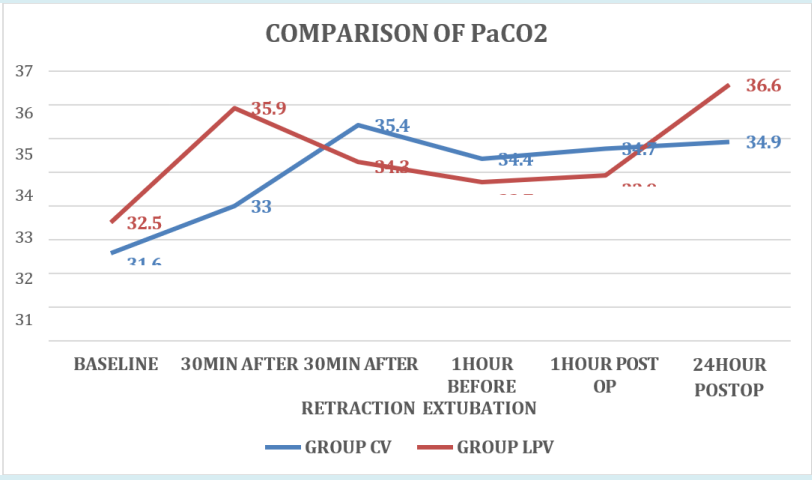


Figure 9: Comparison of $PaCO_2$.

$Etco_2$-$paCo_2$ difference

This was comparable between both groups (Table 8) (Figure 10).

Time intervals	Group CV	Group LPV	p value
Baseline	1.9±4.4	1.5±2.8	0.77
After intubation	4.4±4.5	3.9±3.6	0.11
After abdominal retraction/laparotomy	1.7±2.7	1.3±3.0	0.73
End of surgery	2.97±4.8	1.9±3.5	0.61

Table 8 : Comparison of $Etco_2$ – $paCo_2$ Difference.

Data are shown as mean ± SD or median [interquartile range] as appropriate

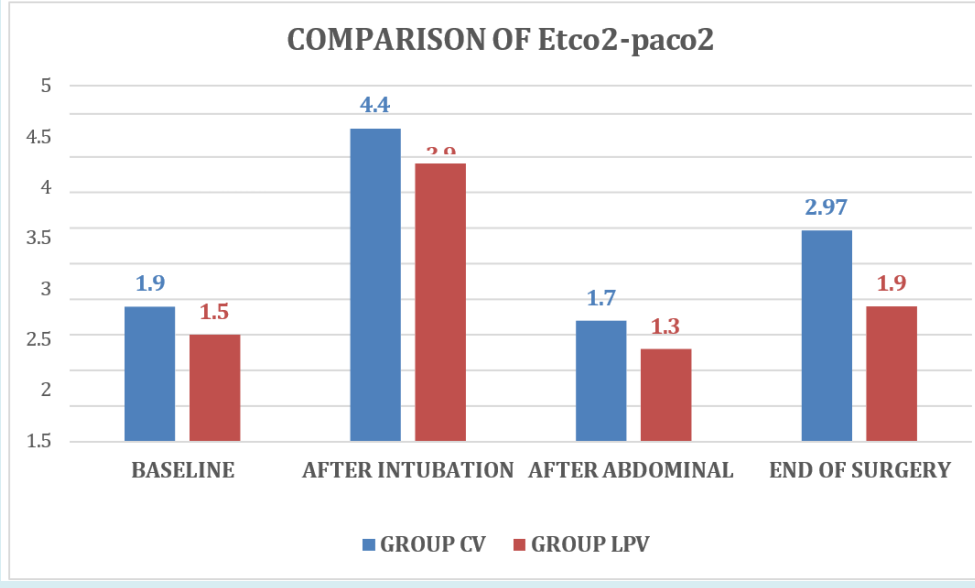


Figure 10: Comparison of $Etco_2$ – $paco_2$.

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Intraoperative Pulmonary Mechanics

Dynamic compliance (C_{dyn})) and static compliance (C_{stat}) were significantly higher at all the intraoperative time points in LPV group as compared to CV group (Table 9) (Figures 11-14).

Time frame	Group	P_{peak} (cmH_2O)	C_{dyn} (mL/cmH_2O)	C_{st} (mL/cmH_2O)	SaO_2 (%)
30 mins post intubation	CV	17 (16-19)	32 (28-39)	41 (34-46)	100 (99-100)
	LPV	15 (15-19)	35 (30-41)	40 (35.1-45.6)	99 (98-100)
	p- value	0.75	0.69	0.77	0.28
30 mins post abdominal retraction	CV	20 (19-21)	27 (24-29)	36 (31.2-40)	99 (99-100)
	LPV	17 (16-19)	33 (30-36)	42 (37-45.1)	99 (98-100)
	p-value	0.02*	0.003*	0.001*	0.36
60 minutes before extubation	CV	22 (19-23)	25 (24-29)	35 (33.1-38)	100 (99-100)
	LPV	17 (16-18)	31 (26-34)	43 (38-47)	100 (99-100)
	p-value	0.001*	0.018*	0.004*	0.71
At extubation	CV	19 (17-20)	31 (29-37)	39 (33-41)	100 (99-100)
	LPV	16 (16-19)	35 (31-42)	44 (37-47)	100 (99-100)
	p-value	<0.001*	0.002*	0.009*	1

Table 9: Comparison of Intraoperative Pulmonary Mechanics.

Data are shown as mean ± SD or median [interquartile range] as appropriate; * p value<0.05

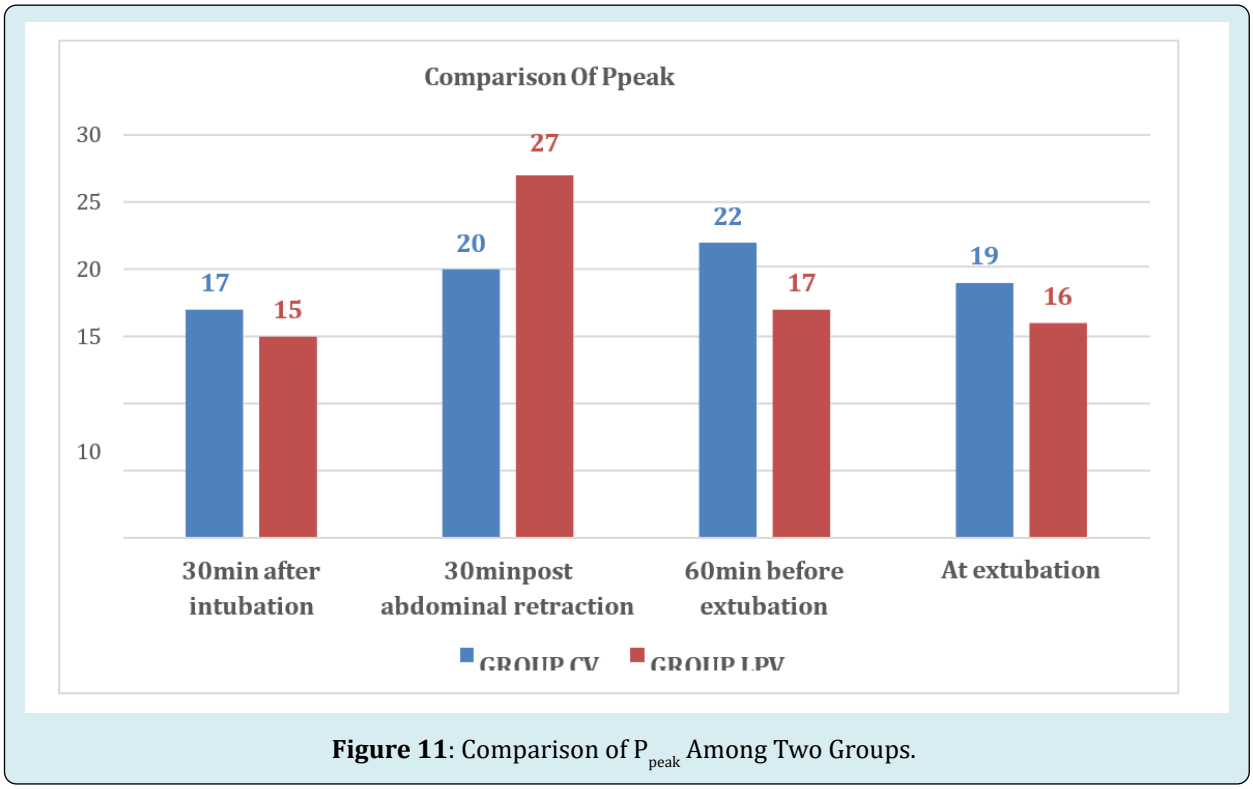


Figure 11: Comparison of P_{peak} Among Two Groups.

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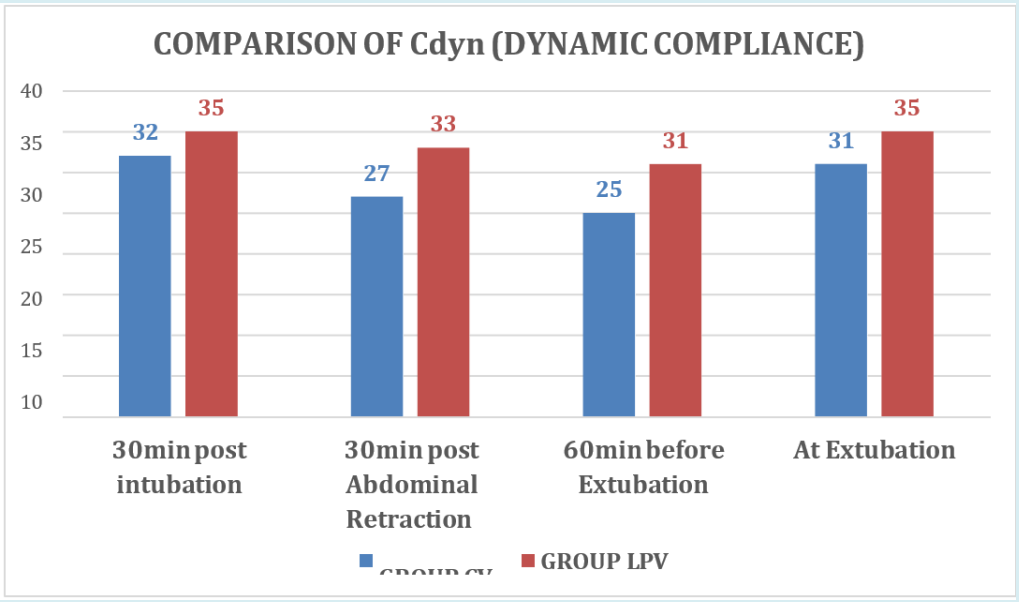


Figure 12: Comparison of C_{dyn}(Dynamic Compliance) Among Two Groups.

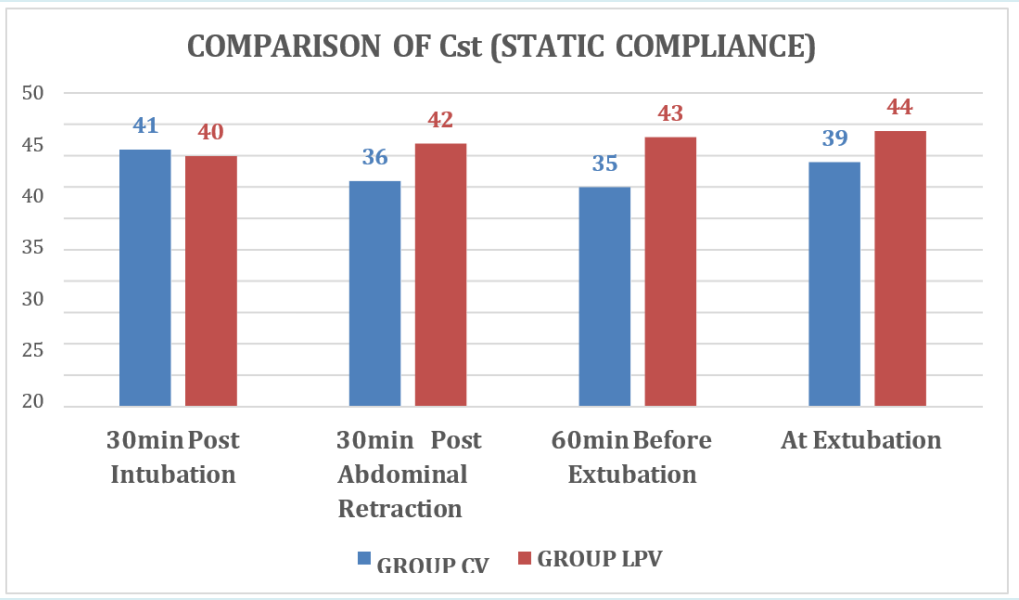


Figure 13: Comparison of C_{st}(Static Compliance) among Two Groups.

Hemodynamic data: was comparable between both groups at all time points (Table 10-13).

Time intervals	Group CV	Group LPV	p value
Baseline	72.65 ±14.7	81.1±16.5	0.14
After intubation	81.6±17.6	82.9±16.6	0.77
After abdominal retraction/laparotom y	84.4 ±17.5	86.4 ±14.2	0.69
End of surgery	84.5 ±17.6	85.3 ±15.1	0.68

Table 10: Comparison of intraoperative HR variation

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Data are shown as mean ± SD or median [interquartile range] as appropriate;

Time intervals	Group CV	Group LPV	p value
Baseline	126.4 ±20	143.9±20.2	0.22
After intubation	104.1±20.4	109.4±19.3	0.81
After abdominal retraction/laparotom y	120.1 ±22	123.2±17.8	0.71

Table 11: Comparison of Intra-Operative SBP Variation.

Data are shown as mean ± SD or median [interquartile range] as appropriate;

Time intervals	Group CV	Group LPV	p value
Baseline	74.5 ±12.0	78.2 ±12.2	0.11
After intubation	73.0±12	71.1±18.2	0.17
After abdominal retraction/laparotomy	70.3±16	72.4±11.8	0.72

Table 12: Comparison of Intra-Operative DBP (Diastolic BP) Variation.

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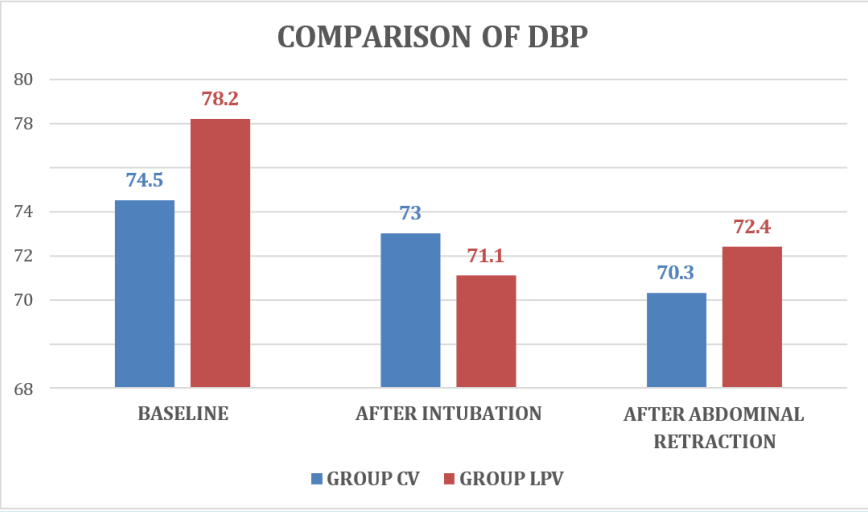


Figure 14: Comparison of DBP.

Time intervals	Group CV	Group LPV	p value
Baseline	93.9±19.1	100±13	0.71
After intubation	89.4±13.0	91.4±17.8	0.61
After abdominal retraction/laparotomy	90.0±18.6	92.8±13.6	0.69

Table 13: Comparison of Intra-Operative MAP Variation.

Data are shown as mean ± SD or median [interquartile range] as appropriate;

Postoperative Pulmonary Complications

There were no differences in incidence of atelectasis as seen by chest X-ray between the two groups after surgery. Length of stay in postoperative care unit was also comparable in both groups (Table 14) (Figure 16).

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X ray parameter	Group CV	Group LPV	p value
normal	26	27	0.08
Interstitial thickening	1	2	0.12
Infiltrates	1	1	0.33
Pleural effusion	1	0	0.42
atelectasis	1	1	0.51

Table 14: Comparison of Post Operative Pulmonary Complications.

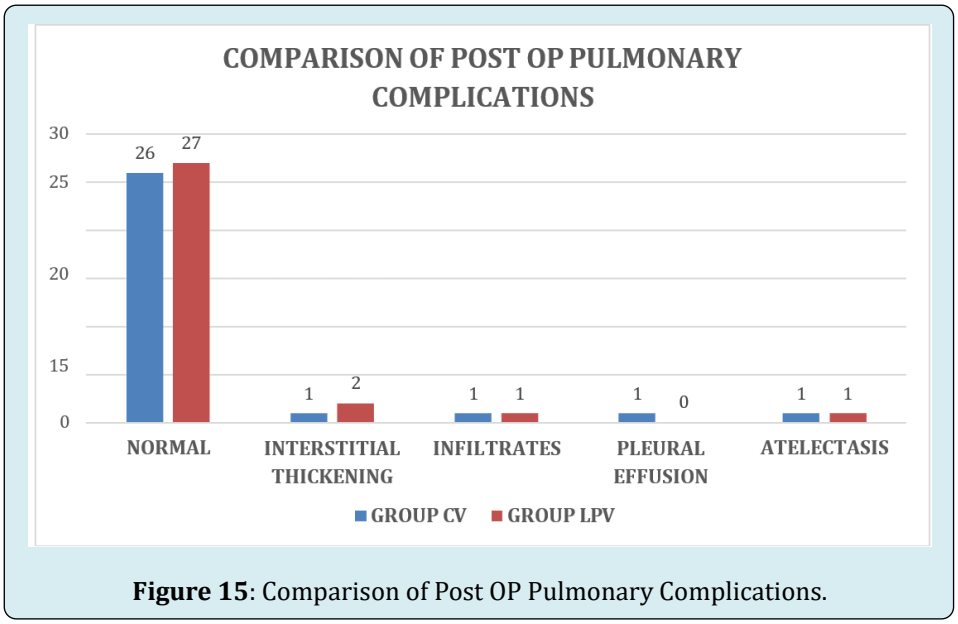


Figure 15: Comparison of Post OP Pulmonary Complications.

Discussion

This study compared two different intraoperative ventilatory strategies to reduce lung injury i.e; conventional ventilation (CV) and lung protective ventilation (LPV) strategy with addition of PEEP and vital capacity recruitment maneuver. The chief findings of this trial were that lung protective ventilation strategy improved intraoperative oxygenation and lung compliance without compromising intraoperative hemodynamic stability. These effects on PaO_2, achieved with recruitment maneuver were limited to the immediate postoperative period. The PaO_2 and PaO_2/FiO_2 were comparable between the two groups at 24hrs postoperatively and there was no difference in the incidence of atelectasis on the first postoperative day.

Intraoperative Trendelenburg positioning has been demonstrated to facilitate atelectasis formation [25,26] by shifting the diaphragm cranially [27-29] thereby decreasing pulmonary compliance, leading to collapse of small airways and alveoli [30,31], increase in lung elastance, static intrinsic PEEP, and total airway resistances. Our study showed that the LPV strategy could partially reverse these deleterious effects of surgery in Trendelenburg position on pulmonary mechanics by preventing the onset of atelectasis and improving dynamic and static compliance. We speculated that high level of PEEP during the recruitment maneuovers could partially counterbalance the cranial shift of the diaphragm caused by Trendelenburg position, retractor application and could induce the corresponding lung expansion. PEEP also prevents the alveoli from repeated opening and collapse23 which may, over a long ventilation period, lead to pulmonary injury.

However high levels of intraoperative PEEP may cause barotrauma in normal lung and result in iatrogenic lung injuries43. The level of PEEP in our study should be well tolerated since the driving pressure in LPV group was kept quite low (<15cmH_2O). A recent study in patients undergoing cardiac surgery who received a protective ventilation strategy comprising of low tidal volume of < 8 ml/kg IBW, modified driving pressure < 16 cmH_2O, and PEEP ≥5 cmH2O, established that modified driving pressure was independently associated with decreased PPCs but V_t < 8 ml/kg and PEEP ≥5 cmH_2O were not High levels of Alveolar-arterial oxygen gradient (A-aO_2) are associated with ventilation-perfusion mismatch, shunting and gas diffusion abnormalities across the alveolar-capillary membrane. Prior

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studies demonstrated A-aO_2 as a useful tool to evaluate intrapulmonary shunt caused by alveolar collapse [32]. In the present study, A-aO2 as a marker of shunting, was significantly lower in the LPV 58group compared to CV group. A similar finding has been reported by Jing Liu, et al. [33] in laparoscopic surgery which essentially replicates the lung mechanics seen in trendelenburg position.

The improved intraoperative oxygenation function in LPV group, however, was at the cost of elevation in $PaCO_2$ and $EtCO_2$, which may result from the low tidal volume used in the group. This hypercapnia however was in line with permissive hypercapnia and the pH was still kept in a normal range [34].

Perioperative lung injury is a major source of postoperative morbidity, prolonged length of ICU stay and avoidable mortality. Many potential inciting factors can lead to this condition, including intraoperative ventilator-induced lung injury. Ventilatory strategies designed to maintain lung expansion and minimize the mechanical shear stresses on lung parenchyma have gained popularity in the management of patients with acute lung injury (ALI). These involve the use of recruitment maneuvers to promote re-expansion of atelectasis, followed by ventilation with relatively high PEEP (to prevent reformation of atelectasis) and lower tidal volumes (to minimize mechanical stresses). Prevention of atelectasis also minimizes barotrauma caused by the repetitive opening and closing of lung units. The goal of these strategies is to maximize the gas exchange and to minimize the risk of ventilator-induced lung injury.

There is an increasing interest to understand the beneficial effects of these strategies for surgical patients, most of whom do not present with any pre-existing lung pathology but may develop areas of atelectasis, acute lung injury shortly after the induction of anaesthesia and due to positioning for surgery and surgical retraction. Patients undergoing upper abdominal surgeries have a higher incidence of PPC. The lung protective strategies like low tidal volume and PEEP have shown to be beneficial in improving postoperative pulmonary function. There is no consensus on whether the lung recruitment maneuvers (LRMs) should be routinely used for anesthetized patients with healthy lungs. Atelectasis occurs with a high incidence of 90% in patients undergoing general anesthesia and can persist to different degrees after surgery. The etiologies of atelectasis formation during intraoperative short-term ventilation in normal lungs are the compression of lung parenchyma [35,36], reabsorption of intra-alveolar gas [37], collapse of small airways [38] and surfactant dysfunction. The unventilated lung areas are more likely to occur near to the diaphragm with a varying incidence of 3 to 6% [39] to 25% [40].

The incidence of atelectasis in our study was fairly low (2 patients in both groups) and there was no difference between the two groups. One of the limitations in our study was that chest x-ray is much less sensitive as compared to CT scan or Ultrasonography in diagnosis of atelectasis. Hence, we could have missed patients with low levels of atelectasis.

Limitations

Firstly, the LPV bundle used in our trial included low tidal volume, high PEEP, coupled with by intermittent lung recruitment maneuvers. Interpretation of the benefits conferred by each component is difficult whether it is the decrease in tidal volume, or the high level of PEEP or the recruitment maneuvers or both. Moreover, to what extent low tidal volumes succeeded in preventing barotrauma and volutrauma could not be analyzed. Secondly, all patients in LPV group received the same level of PEEP and individual titration of the degree of PEEP was not done. Thirdly, we did not utilize Ultrasonography or computed tomography, to determine the occurrence of atelectasis and pulmonary morphological alterations which could have led to underestimation.

Review of Literature

The literature was reviewed using PubMed for the following topics:

- Effects of Trendelenburg position on the respiratory system.
- Effects of general anaesthesia on respiratory mechanics and gas exchange.
- Effect of positive end-expiratory pressure (PEEP) in open Abdominal surgeries.
- Intraoperative lung-protective ventilation strategies in open Abdominal surgeries.

With key words: “Trendelenburg”; “Respiratory mechanics”; “PEEP”; “Recruitment Maneuvers”.

Effects of Trendelenburg Position on the Respiratory System

Xue S, et al. [41-43] found that compared to general surgery group(42) the robot-assisted group(46) presented significantly higher airway pressure and lower lung compliance during surgery($P<0.001$). This significantly impairs postoperative diaphragm function, which does not recover to preoperative levels at PACU discharge. Elevated levels of serum CC16 after surgery suggest potential lung injury. The adverse effects may be attributed to the prolonged Trendelenburg position and pneumoperitoneum during laparoscopic surgery.

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Suh MK, et al. [1-5] demonstrated that pneumoperitoneum significantly reduced dynamic lung compliance and increased airway pressures, while Trendelenburg positioning itself did not alter these parameters.

Similarly Rauh R, et al. [6] reported reduced compliance and increased airway pressures at 15 mmHg pneumoperitoneum, which normalized after deflation. Park JS, et al. [7] found that a 20° head-down tilt with pneumoperitoneum variably affected compliance and airway resistance. Mitsuhashi A, et al. [8] observed increased mean and peak airway pressures in obese patients undergoing robotic hysterectomy in steep head-down tilt.

Lu LL, et al. [9] showed that a −30° head-down tilt reduced FVC, FEV1, and MVV, indicating impaired pulmonary ventilation. Collectively, these studies highlight the adverse impact of Trendelenburg positioning, especially when combined with pneumoperitoneum, on respiratory mechanics.

Effects of General Anaesthesia on Respiratory Mechanics and Gas Exchange

General anaesthesia impairs pulmonary function through multiple mechanisms. Rehdar K, et al. [10,11] described impaired oxygenation and CO_2 elimination due to altered chest wall mechanics and reduced FRC. Hedensteirna G [15] emphasized that anaesthesia promotes airway closure and atelectasis, leading to ventilation–perfusion mismatch. Zeng C, et al. [12] outlined biological consequences of atelectasis, including inflammation and alveolar capillary barrier damage. Lagier D, et al. [13] demonstrated that atelectasis during surgery impairs gas exchange and predisposes to postoperative complications. Rothen HU, et al. [14] and Hedensteirna G [15] quantified that atelectasis and airway closure explain up to 74% of gas exchange impairment during routine anaesthesia. Tokics L, et al. [17] showed that PEEP can diminish atelectasis but not necessarily shunt. Gunnarsson L, et al. [18] highlighted age-related susceptibility, with older patients experiencing greater oxygenation impairment.

Grieco DL, et al. [19] demonstrated that compliance and driving pressure during anaesthesia reflect aerated lung volume and dynamic strain, modulated by PEEP. These findings underscore the central role of anaesthesia in promoting atelectasis and impaired oxygenation.

Effect of Positive End-Expiratory Pressure (PEEP) in Open Abdominal Surgeries

PEEP has been studied extensively as a strategy to mitigate intraoperative atelectasis. Pereira SM, et al. [20] demonstrated that individualized, impedance-guided PEEP improved intraoperative oxygenation and reduced postoperative atelectasis without compromising hemodynamics. Imberger G, et al. [21], in a meta-analysis of eight randomized trials, found that PEEP improved PaO_2/FiO_2 ratios and reduced atelectasis on postoperative day one, though mortality was unaffected. Fernandez Bustamante A, et al. [22] showed that individualized PEEP reduced driving pressure and improved static compliance during abdominal surgery. These studies suggest that tailoring PEEP to individual respiratory mechanics can optimize intraoperative ventilation and reduce postoperative pulmonary complications.

Intraoperative Lung Protective Ventilation Strategies in Open Abdominal Surgeries

Several randomized and comparative studies have evaluated the role of lung protective ventilation (LPV) strategies in open abdominal surgery.

Pi X, et al. [23] compared three ventilation strategies: high tidal volume (9 ml/kg IBW) with zero end-expiratory pressure (ZEEP), low tidal volume (7 ml/kg IBW) with 8 cmH_2O PEEP, and low tidal volume with PEEP plus recruitment maneuvers. The group receiving low tidal volume with PEEP and recruitment demonstrated superior postoperative pulmonary function, particularly higher FEV1 on the first postoperative day, highlighting the benefits of combining low tidal volume with alveolar recruitment.

Severgnini P, et al. [24] conducted a randomized trial and found that patients ventilated with protective strategies (low tidal volume and moderate PEEP) had improved postoperative pulmonary function and fewer radiographic signs of atelectasis compared to conventional ventilation.

Zhang ZF, et al. [44] investigated protective ventilation in abdominal surgery and reported improved intraoperative oxygenation and reduced postoperative pulmonary complications, reinforcing the evidence that LPV strategies enhance perioperative outcomes.

Sun M, et al. [45] further observed that for patients undergoing laparoscopic surgery, the use of protective lung ventilation is effective in reducing the incidence of lung injury and pulmonary infection. Implementation of a low tidal volume plus moderate positive end-expiratory pressure strategy reduces the risk of postoperative pulmonary complications.

Most of these Lung protective ventilation studies were done in Laparoscopic and open Abdominal surgeries, and not particularly in Trendelenburg position open abdominal

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surgeries. Results showed improvement of intraoperative lung oxygenation and reduced post operative pulmonary complications, but they did not study about pulmonary mechanics and post operative oxygenation. So, in this study our aim was to compare Conventional Ventilation (CV) and Lung Protective Ventilation (LPV) both intra and post operatively and improve lung function in patients undergoing open Abdominal surgeries in Trendelenburg position.

Conclusion

Lung protective ventilation strategy comprising of low tidal volumes and PEEP with recruitment maneuvers, or a combination of these two, is an important determinant of protection in intraoperative mechanical ventilation. In non-obese patients undergoing open abdominal surgery in Trendelenburg position, mechanical ventilation when performed with low tidal volumes (7 ml/kg) combined with PEEP and intermittent recruitment maneuver improves Pao_2/Fio_2 without causing significant hemodynamic instability. Further studies are warranted to guide intraoperative mechanical ventilation in a broader spectrum of patients undergoing surgical interventions in the Trendelenburg position.

Declaration of Conflicting Interest

There are no conflicts of interest.

Funding Statement

Nil

Ethical Approval and Informed Consent Statements

Institutional ethics committee approval with Review letter No.EC/NIMS/2888/2021, 58th ESGS No. 1262/2021

Data Availability Statement

The datasets generated and analysed during the current study are available from the corresponding author for 5 years from publication.

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