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Research Article

The influence of Lung re-expansion at different time points on Respiratory mechanics and Postoperative Lung Atelectasis in Gynecological Laparoscopic Surgery

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Abstract

Background: To investigate the effects of lung recruitment maneuver under lung ultrasound score (LUS) evaluation at different time points on respiratory mechanics and postoperative atelectasis during gynecological endoscopic surgery.

Methods: Sixty patients aged ≥ 18 years, with a BMI of<30 kg/m^2 and ASA I ～II, underwent elective gynecological endoscopic surgery from October 2021 to October 2022 were selected. The patients were divided into three groups using a random number table method, with 20 cases in each group: lung recruitment maneuver during pneumoperitoneum group (group A), lung recruitment maneuver after Trendlenburg position group (group B), and non-lung recruitment maneuver group (group C). Group A: Immediately after the set up of pneumoperitoneum, started the first lung recruitment maneuver (using PEEP incremental method for lung recruitment maneuver: Set the inspiratory pressure (Δ P) at 20cmH_2O in PCV mode, increased 5cmH_2O PEEP every 5 breaths to achieve a peak inspiratory pressure of 40cmH_2O, and kept the breathing for 10 times. Then, decreased 5cmH_2O PEEP every 5 breathing cycles until it reached the level before lung recruitment maneuver and changed to PCV-VG mode. Afterwards, the lung recruitment maneuver was performed once an hour. Group B: Immediately performed the first lung recruitment maneuver after the Trendlenburg position was set up. Afterwards, also by the PEEP incremental method, lung recruitment maneuver was performed once an hour. Group C: No lung recruitment maneuver throughout the entire process. Recorded the HR and MAP at the time points of establishing stable mechanical ventilation after intubation (T1), 5 minutes after pneumoperitoneum set up (T2), 5 minutes after Trendelenburg position set up (T3), 4 minutes after pneumoperitoneum cessation (T4), and 5 minutes after supine position set up (T5), and conducted blood gas analysis. Recorded PaO_2 and $PaCO_2$, calculated oxygenation index (OI) and intrapulmonary shunt rate (Qs/Qt; Qs/Qt=alveolar-arterial oxygen partial pressure difference × 0.0031/(alveolar-arterial oxygen partial pressure difference × 0.0031+5) × 100%). Recorded indicators of respiratory mechanics such as peak airway pressure (Ppeak), plateau pressure (Pplat), and dynamic lung compliance (Cdyn) from T1 to T5 and calculated Δ P; Recorded the LUS before anesthesia (T0), before tracheal catheter removal (T6), and 30 minutes after tracheal catheter removal (T7) and the occurrence of atelectasis. Recorded the incidence of pulmonary complications (atelectasis, pneumothorax, respiratory failure, aspiration pneumonia, respiratory infection, pleural effusion, bronchial asthma) in 3 days after operation.

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Results

Compared with T0, the LUS of the three groups at T5 and T6 was significantly increased ($P<0.05$), while the LUS and the incidence of atelectasis in group C at T5 and T6 was significantly increased ($P<0.05$) compared to groups A and B. Compared with T1, Ppeak and ΔP of the three groups significantly increased while Cdyn significantly decreased at T2 to T5 ($P<0.05$). Compared group A with group B and C at T2, Ppeak and ΔP significantly decreased while Cdyn significantly increased ($P<0.05$); During T3-T5, compared between groups A, B and C, Ppeak and ΔP significantly decreased, while Cdyn significantly increased ($P<0.05$). There was no statistically significant difference between group A and B at T3. There was no statistically significant difference in the incidence of postoperative pulmonary complications among the three groups.

Conclusion

Protective ventilation after lung recruitment maneuver can improve respiratory mechanics and oxygenation during laparoscopic gynecological surgery, also is beneficial in terms of postoperative LUS and incidence of atelectasis.

Keywords: Lung ultrasound score; Lung recruitment maneuver; Protective ventilation; Laparoscopic gynecological surgery; Respiratory mechanics

Introduction

Laparoscopic surgery is currently the main surgical mode in gynecology, which typically requires insufflation and special positioning to provide a satisfactory surgical field. Insufflation can cause cephalad diaphragmatic displacement and partial lung collapse at the posterior lung, altering respiratory mechanics, increasing airway pressure, and decreasing static compliance of the lung and chest wall [1]. The Trendelenburg position has adverse effects on cardiopulmonary function and increases the risk of postoperative pulmonary complications (PPCs) [2]. Studies have shown that perioperative lung-protective ventilation can reduce the incidence of PPCs [3]. Perioperative lung-protective ventilation involves using small tidal volumes (VT) [4], appropriate positive end-expiratory pressure (PEEP), and lung recruitment maneuvers (RM). Previous research [5,6] has observed that sequential lung recruitment combined with lung-protective ventilation can improve driving pressure and lung efficiency during laparoscopic colorectal surgery. The aim of this study is to observe the effects of lung recruitment combined with low VT and moderate-level PEEP ventilation on driving pressure (ΔP), lung ultrasound score (LUS), and PPCs at different time points in gynecological surgery patients.

Materials and Methods

General Information

This study was approved by the Hospital Medical Ethics Committee (XM-2021-010), and informed consent was obtained from the patients or their relatives. Patients scheduled for elective laparoscopic gynecological surgery between October 2021 and October 2022 were selected. Inclusion criteria were as follows: Trendelenburg position (head down, feet up 30º), age 18 years or older, no significant abnormalities in lung function, no difficult airways, asthma, or chronic obstructive pulmonary disease, and ASA I to Π grade. Exclusion criteria included ASA III or higher, severe respiratory or cardiovascular diseases, liver or kidney impairment, chest or spine deformities, obesity ($BMI>28Kg/m^2$), psychiatric or cognitive abnormalities, and participation in other clinical studies within the last 3 months. Patients were excluded if preoperative lung ultrasound indicated lung collapse, if conversion to open surgery was required, or if severe subcutaneous emphysema or pneumothorax occurred postoperatively, affecting the acquisition of lung ultrasound images.

Anesthesia Method

Upon confirming patient identification from three different sources, the upper limb intravenous access was established. Routine monitoring of ECG, HR, SpO_2, and BIS was initiated. Radial artery cannulation was performed to enable invasive arterial blood pressure monitoring and arterial blood sampling for blood gas analysis. Anesthesia induction was carried out with 100% oxygen inhalation for 5 minutes, followed by the administration of 0.5 μg/kg sufentanil, 2.0 mg/kg propofol, and 0.8 mg/kg rocuronium bromide. After tracheal intubation, mechanical ventilation was initiated. Intravenous infusion pumps were used to administer propofol at a rate of 4-6 $mg.kg^{-1}.h^{-1}$ and remifentanil at a rate of 0.1-0.3 $\mu g.kg^{-1}.min^{-1}$ to maintain the BIS between 40 and 60. Intermittent boluses of cisatracurium at 0.1 mg/kg were administered as needed. Crystalloid fluids were the main choice for intraoperative fluid administration. In case of a decrease in mean arterial pressure (MAP) by more than 20% from baseline, colloid fluids and vasopressors were administered as appropriate. After the surgery. the patient was transferred to the post-anesthesia care unit. Tracheal extubation was performed once the criteria for extubation were met.

Grouping and Processing

Random numbers are generated by the computer and distributed into three groups in a 1:1:1 ratio. The groups are as follows: lung recruitment with pneumoperitoneum (Group A), lung recruitment after Trendelenburg positioning (Group B), and no lung recruitment (Group C). Participants are assigned to each group based on the random numbers they receive. Ventilation is performed using pressure-controlled

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ventilation with volume guarantee (PCV-VG) mode. The settings include a tidal volume (VT) of 6 ml/kg, positive end-expiratory pressure (PEEP) of 5 cmH_20, an oxygen concentration (FiO_2) of 60%, and an inspiratory-expiratory ratio (I:E) of 1:2. The respiratory rate (RR) is adjusted to maintain end-tidal carbon dioxide ($PEtCO_2$) between 35 to 45 mmHg.

Lung Recruitment Strategy

Group A: Lung recruitment with pneumoperitoneum. Lung recruitment is initiated immediately after pneumoperitoneum is established and is repeated once every hour. The recruitment is carried out using the PEEP increment method [7,8] in pressure-controlled ventilation (PCV) mode, with an inspiratory pressure (ΔP) set at 20 cmH2O. PEEP is increased by 5cmH_2O every 5 breaths until the inspiratory peak pressure reaches 40 cmH_2O, and this level is maintained for 10 breaths. Subsequently, PEEP is decreased by 5 cmH_2O every 5 breath cycles until it reaches the pre-recruitment level. After this, the ventilation mode and parameters are switched back to PCV-VG. Group B: Lung recruitment after Trendelenburg positioning. Lung recruitment is initiated immediately after positioning, and it is repeated once every hour. The recruitment method is the same as in Group A, using the PEEP increment method. Group C: No lung recruitment throughout the procedure. Lung recruitment is not used in this group. Anesthesia administration and recruitment procedures are carried out by experienced senior residents according to the given protocol. Data collection is the responsibility of dedicated research personnel who are not involved in the anesthesia process and are unaware of the specific ventilation strategies.

Lung Ultrasound (LUS) Evaluation Method

Lung ultrasound examination is performed using a Mindray ultrasound system with a convex array transducer of 2-5 MHz. The examination is carried out by specifically trained personnel. The chest wall is divided into upper and lower zones at the level of the nipples and further subdivided into 12 regions using bilateral parasternal lines, anterior axillary lines, posterior axillary lines, and paravertebral lines to define the anterior, lateral, and posterior zones. The evaluation is based on the Modified Lung Ultrasound Scoring System [9], with a total score of 36 for the 12 regions. A higher score indicates more severe lung ventilation impairment. Scoring criteria are as follows: 0 points for normal lung ventilation signs or fewer than 3 B-lines; 1 point for 3 or more B-lines or the presence of subpleural consolidations separated by normal pleural lines; 2 points for multiple confluent B-lines or the presence of multiple subpleural consolidations separated by thickened or irregular pleural lines; 3 points for white lung or subpleural consolidations larger than 1 cm × 2 cm. Lung atelectasis is defined as any region showing signs of atelectasis (LUS score ≥ 2) among the 12 examined regions.

Observation Indices

Record the following parameters at specific time points: T1 - after stable mechanical ventilation is established following endotracheal intubation, T2 - 5 minutes after pneumoperitoneum is completed, T3 - 5 minutes after assuming the Trendelenburg position, T4 - after deflating pneumoperitoneum, T5 - 5 minutes after returning to the supine position. Monitor heart rate (HR) and mean arterial pressure (MAP) simultaneously with blood gas analysis, recording values of arterial oxygen partial pressure (PaO_2) and arterial carbon dioxide partial pressure ($PaCO_2$). Calculate the oxygenation index (OI) and pulmonary shunt fraction (Qs/Qt), where Qs/Qt = (alveolar-arterial oxygen tension difference × 0.0031) / (alveolar-arterial oxygen tension difference × 0.0031 + 5) × 100%.

Additionally, record respiratory mechanics parameters such as peak airway pressure (Ppeak), plateau airway pressure (Pplat), and dynamic lung compliance (Cdyn) at time points T1 to T5, and calculate ΔP (difference in airway pressure between Ppeak and Pplat).

Furthermore, document lung ultrasound (LUS) findings and occurrences of lung atelectasis at three specific time points: T0 - before anesthesia induction, T6 - before extubation at the end of surgery, and T7 - 30 minutes after extubation.

Monitor and record the occurrence of pulmonary complications (atelectasis, pneumothorax, respiratory failure, aspiration pneumonia, respiratory tract infection, pleural effusion, bronchial asthma) within 7 days after the surgery.

Statistical analysis

The primary outcome measure for statistical analysis is the lung ultrasound (LUS) score at time point T6. Based on the preliminary trial results, the LUS scores at T6 for Groups A, B, and C are (7.5±0.5), (8.3±1.2), and (10.4±1.6), respectively. Assuming a significance level (α) of 0.05 (two-tailed), a power of 0.9 (1-β), and a dropout rate of 20%, the sample size is calculated to be 48 cases per group using PASS 15.0 software. To enhance the testing efficiency, this study will include a total sample size of 60 cases, with 20 cases in each group.

The data will be analyzed using SPSS 26.0 software

Normally distributed continuous variables will be presented as mean ± standard deviation (± s). Between-group comparisons will be performed using independent samples t-test, and within-group comparisons will use repeated measures analysis of variance (ANOVA). For non-normally distributed continuous variables, the data will be presented as median (M) and interquartile range (IQR). Between-group comparisons will be conducted using non-parametric tests. Categorical data will be presented as counts (percentage %),

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and between-group comparisons will be performed using the chi-square (χ2) test. Statistical significance will be set at P<0.05.

Results

There were no exclusions or dropouts in this study, and a total of 60 patients were included in the analysis. There were no statistically significant differences in age, ASA classification, BMI, pneumoperitoneum time, surgery time, intraoperative fluid replacement volume, and use of vasoactive drugs among the three groups (P > 0.05) (Table 1).

Compared to T1, Ppeak and ΔP significantly increased, while Cdyn significantly decreased in all three groups at T2 to T5 (P<0.05). At T2, Group A showed significantly decreased Ppeak and ΔP, and significantly increased Cdyn compared to Groups B and C (P<0.05). From T3 to T5, both Group A and Group B demonstrated significantly decreased Ppeak and ΔP, and significantly increased Cdyn compared to Group C (P<0.05). At T3, there was no significant statistical difference in Ppeak, ΔP, and Cdyn between Group A and Group B (Table 2).

The Qs/Qt (shunt fraction) significantly increased in all three groups after pneumoperitoneum and head-down positioning, and the increase was more pronounced with longer pneumoperitoneum time (P<0.05). Moreover, in Group C, the increment gradually expanded with time, while in Groups A and B, the Qs/Qt at T2 and T3 was significantly lower than in Group C (P<0.05). The $PaCO_2$ and $PETCO_2$ gradually increased with prolonged pneumoperitoneum time in all three groups (P>0.05), and there were no statistically significant differences between groups (P>0.05). The OI (oxygenation index) showed no significant changes in Group C, but it gradually increased in Groups A and B. At T2 and T5, Group A had a significantly higher OI than Groups B and C, with statistically significant differences (P<0.05).

LUS score

Compared with T0, the LUS scores of the three groups at T6 and T7 were significantly higher (P<0.05). The LUS scores and postoperative lung collapse rate of group C were significantly higher compared to groups A and B at T6 and T7 (P<0.05, Table 4). Postoperative follow-up: There were

Table 1: Comparison of General Information (x ± s)

Group	Cases	Age (years)	ASA I/II	BMI (kg/m^2)	Pneumoperitoneum time (min)	Surgery time (min)	Intraoperative fluid replacement volume	Application of vasoactive drugs cases (%)
Group A	20	48.05±1.4	Mar-17	21.7±2.1	118.4±46.4	131.1±21.4	1480±435^{a}	3 (15)
Group B	20	48.10±1.4	Jun-14	22.3±2.0	113.4±35.1	120.4±27.5	1360±365^{a}	2 (10)
Group C	20	48.25±1.3	Mar-17	21.7±2.1	107.2±36.7	125.7±23.6	1623±451	3 (15)
F		0.116	2	0.68	0.399	0.806	10.036	
P		0.891	1	0.511	0.673	0.451	0.000	

Note. Compared to Group C, ^{a}P<0.05.

Table 2: Comparison of Ppeak ΔP and Cdyn (mean ± standard deviation x ± s)

Index	Group	Cases	T1	T2	T3	T4	T5
Ppeak	Group A	20	15.43±0.69	20.41±0.80^{ad}	20.70±0.55^{ad}	20.70±0.50^{ad}	20.60±0.71^{ad}
(mmHg)	Group B	20	15.35±0.59	22.88±0.75^{ad}	20.50±0.61^{ad}	20.50±0.50^{ad}	21.41±0.52^{ab}
	Group C	20	15.39±0.57	22.88±1.33^{abc}	22.55±0.60^{abc}	22.88±0.91^{abc}	21.50±0.50^{ab}
	F		0.063	26.757	78.687	98.545	11.027
	P		0.941	0	0	0	0
ΔP	Group A	20	10.31±0.55	15.81±0.81^{ad}	15.41±0.50^{ad}	15.49±0.51^{ad}	15.65±0.70^{ad}
(mmHg)	Group B	20	10.31±0.55	18.92±0.73^{ad}	15.45±0.58^{ad}	15.49±0.51^{ad}	16.40±0.50^{ab}
	Group C	20	10.36±0.58	18.35±1.08^{abc}	17.30±0.57^{abc}	18.00±0.90^{abc}	16.45±0.50^{ab}
	F		0.1	50.774	78.688	98.555	11.031
	P		0.904	0	0	0	0
Cdyn	Group A	20	39.65±4.75	25.73±2.02^{ad}	26.45±2.67^{ad}	26.26±2.45^{ad}	25.95±2.51^{ad}
	Group B	20	38.52±2.89	21.99±1.01^{ad}	25.67±1.22^{ad}	25.66±1.30^{ad}	25.49±1.25^{ab}
	Group C	20	38.72±3.70	21.88±1.45^{abc}	23.16±1.88^{abc}	22.30±1.61^{abc}	24.35±1.89^{ab}
	F		0.497	36.098	15.287	28.252	5.216
	P		0.611	0	0	0	0.008

Note: a. P<0.05 compared to T0. b. P<0.05 compared to Group A. c. P<0.05 compared to Group B. d. P<0.05 compared to Group C.

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Table 3: Comparison of $PETCO_2$, $PaCO_2$, and Oxygenation Index (mean ± standard deviation, x ± s)

Index	Group	Cases	T1	T2	T3	T4	T5
$PaCO_2$	Group A	20	35.8±5.5	35.8±4.0	36.1±3.6	36.6±5.3	36.1±5.0
(mmHg)	Group B	20	36.3±4.7	36.6±4.1	36.1±4.4	37.3±3.7	37.6±3.5
	Group C	20	36.5±4.5	35.8±3.3	36.3±3.5	37.2±3.5	37.0±3.2
	F		2.837	0.577	0.999	0.268	0.012
	P		0.065	0.565	0.374	0.767	0.988
$PETCO_2$	Group A	20	34.6±3.6	30.7±1.8^a	32.8±2.5^a	32.8±4.1^d	33.3±3.3
(mmHg)	Group B	20	33.8±4.0	33.9±1.5^b	31.4±2.7^{ab}	32.5±3.3^d	33.5±3.5
	Group C	20	34.2±4.5	34.7±3.4^b	35.5±3.3^b	36.2±3.5^b	36.3±2.6^b
	F		2.418	24.163	8.211	9.108	2.899
	P		0.099	0	0.001	0	0.063
OI	Group A	20	478.8±75.5	512.9±57.9	517.3±70.5^d	512.9±57.9	523.3±66.2^{ab}
	Group B	20	474.5±67.3	500.9±56.9	516.3±61.5^d	510.9±56.9	496.3±58.8
	Group C	20	468.3±71.5	491.9±64.1	487.5±59.3^{bc}	491.9±64.2	492.1±54.1
	F		0.888	0.835	2.269	0.118	6.666
	P		0.418	0.44	0.111	0.888	0.002
Qs/Qt	Group A	20	7.8±0.9	10.3±2.8^a	12.3±2.5^{ad}	13.0±4.1^{ad}	10.0±3.3^{ad}
(%)	Group B	20	7.9±0.9	11.8±3.3^a	10.8±2.3^{ad}	13.1±3.6^{ad}	13.2±3.6^{ad}
	Group C	20	7.4±1.2	11.5±3.3^a	15.3±2.6^{abc}	18.6±3.9^{abc}	18.6±3.7^{abc}
	F		2.27	1.738	7.329	20.195	17.795
	P		0.112	0.185	0.001	0	0

Note: a, P<0.05 compared to T0. b. P<0.05 compared to Group A. c. P<0.05 compared to Group B. d. P<0.05 compared to Group C.

Table 4: Comparison of Lupus (LUS) and postoperative atelectasis at different time points in three patient groups.

Index	Group	Cases	T0	T6	T7
LUS	Group A	20	1(1-2)	6(5-7)^a	7(5-8)^a
(min)	Group B	20	2(1-2)	7(6-10)^a	8(7-10)^a
	Group C	20	1(0-3)	9(7-11)^{ab}	9(8-11)^{ab}
Atelectasis of lung Example (%)	Group A	20	-	4(20)	7(35)
	Group B	20	-	5(25)	8(40)
	Group C	20	-	12(60)^b	15(75)^b

Note: Compared with T_0, $^a P< 0.05$ when compared with group A, and $^b P< 0.05$.

5 cases (25%) in group A, 5 cases (23.81%) in group B, and 6 cases (28.57%) in group C that experienced nausea and vomiting, with no statistically significant difference between the groups. There were no significant differences in hospital stay among the three groups. Pulmonary complications: There were no cases of lung infection in groups A and B, while group C had 1 case (4.76%) of lung infection. Within 3 days after surgery, group A had 1 case (5%) of lung infection and 1 case (5%) of lung collapse, group B had 2 cases (10%) of lung infection and 1 case (5%) of pleural effusion, and group C had 2 cases (10%) of lung infection and 2 cases (10%) of lung collapse. There was no statistically significant difference in the overall incidence of postoperative pulmonary complications among the three groups.

Discussion

This study compared lung-protective ventilation strategies (low tidal volume, moderate PEEP, no lung recruitment) with two different lung recruitment strategies at different time points: lung recruitment after pneumoperitoneum (lung recruitment immediately after pneumoperitoneum and regularly every hour) and lung recruitment after positioning in Trendlenburg position (lung recruitment immediately after pneumoperitoneum and positioning in Trendlenburg position and regularly every hour). We found that after pneumoperitoneum, Ppeak and ΔP significantly increased, while Cdyn significantly decreased. Although lung recruitment did not restore to normal levels, Ppeak and ΔP

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significantly decreased, and Cdyn significantly improved. Lung recruitment immediately after pneumoperitoneum weakened the effect of lung recruitment, but still significantly improved it. The instantaneous effect of lung recruitment after positioning was more significant than that after pneumoperitoneum, but there were no statistically significant changes in Ppeak, ΔP, and Cdyn, and the subsequent effects were similar in both groups. Lung ultrasound (LUS) scores also confirmed that LUS significantly increased after pneumoperitoneum, indicating that pneumoperitoneum is not conducive to lung expansion and is associated with a significantly higher incidence of postoperative lung collapse. This suggests that protective ventilation after lung recruitment can improve respiratory system mechanics, driving pressure, and lung efficiency, reduce driving pressure, and lower the incidence of postoperative pulmonary complications. Lung recruitment at different time points has a significant short-term effect, and the sustained effects are similar.

Under laparoscopic gynecological surgery, pneumoperitoneum and steep Trendelenburg position are usually required to provide a satisfactory surgical field of view. During carbon dioxide pneumoperitoneum, increased intra-abdominal and airway pressure occurs. High intra-abdominal pressure is transmitted through the diaphragm, causing an increase in intrathoracic pressure and resulting in diaphragmatic displacement towards the head. This leads to reduced expansion of the posterior part of the lungs, decreasing the formation of lung atelectasis and altering lung mechanics. As a result, static compliance (Cdyn) of the lungs and chest wall is reduced, and changes in respiratory mechanics are correlated with clinical changes. When the pneumoperitoneum pressure is 12mmHg, Cdyn decreases by 10% per kilogram of body weight. Decreased end-expiratory lung volume reduces lung capacity and impairs oxygenation function, leading to ventilation-perfusion mismatch and becoming a high-risk factor for pulmonary complications such as atelectasis. The steep Trendelenburg position exacerbates the aforementioned changes.

The settings of protective ventilation VT and PEEP, as well as recruitment maneuvers (RM), are important focus points during the perioperative period. Individualized PEEP has been shown to be more effective in reducing the incidence and severity of lung collapse compared to fixed PEEP. Although extensive research has been done on optimizing PEEP using lung compliance, transpulmonary pressure, and electrical impedance tomography, the ideal method for setting individualized PEEP remains unclear. Research has shown that protective ventilation should be regulated by driving pressure, and obtaining PEEP through titration with the minimal driving pressure under the premise of fixed low tidal volume may be an effective strategy for reducing postoperative lung collapse. It is widely believed that low ΔP (driving pressure) can optimize the strategy of protective ventilation, protecting alveoli from the adverse effects of overdistension, and thereby reducing the incidence of postoperative lung complications. Lung recruitment is an important component of lung-protective ventilation strategies. It can prevent lung collapse by maintaining airway patency during pneumoperitoneum and ensuring adequate gas exchange at the end of expiration. However, the adjustment of lung recruitment should be based on the patient's condition, surgical characteristics, and position. We observed that after pneumoperitoneum and head-down tilt of 300, both Ppeak and ΔP increased significantly, while Cdyn decreased significantly. After lung recruitment, both Ppeak and ΔP decreased significantly, while Cdyn increased significantly. Lung recruitment with PEEP increases the gas exchange of lung units while limiting the impact on hemodynamics. However, the elastic recoil of the chest wall, intra-abdominal pressure, and specific positions can compress and reduce the ventilated lung units. Therefore, lung recruitment should be performed every hour. A recent meta-analysis involving over 2000 patients studied the correlation between ΔP per cmH_2O and the risk of postoperative pulmonary complications, with an odds ratio of 1.16 [10,11].This is consistent with the results of Xie Ya-ying et al. It is also similar to the results of the IMPROVE trial by Futier et al. [3]. Although the PROVHILO trial showed no reduction in postoperative complications when comparing 12cmH_2O PEEP combined with RM to 2cmH_2O PEEP without lung recruitment during open abdominal surgery, the former had significantly better Cdyn during surgery [44 (35~54) vs 34 (27~41)]. Some commentaries have suggested that the intervention group in PROVHILO had excessive 12cmH2O PEEP and insufficient lung recruitment. Recent studies on personalized PEEP strategies [12-20] have also shown significant decreases in ΔP, intraoperative hypoxia, postoperative complications, and pulmonary infections with the combined use of lung recruitment.

Lung recruitment also improves Qs/Qt. After lung recruitment, the Qs/Qt in the two groups was significantly lower than that in the group without lung recruitment, indicating that lung recruitment can reduce intrapulmonary shunting. At the same time, the expanded alveoli participate in more gas exchange. This is consistent with the research results of Zhou Yannan et al. [21], who used lung recruitment and PEEP to reduce intrapulmonary shunting and improve lung function in elderly patients. Similar to the study by Ahn et al. [22] that lung recruitment can effectively reduce alveolar collapse, reduce ventilation-perfusion mismatch, and improve patients' oxygenation function, we found that earlier lung recruitment may have better effects.

With the widespread use of lung ultrasound examination, ultrasound can accurately differentiate between lung consolidation and pleural effusion, and can significantly improve the identification of artifacts, improving the differential diagnosis of lung diseases [23]. Lung ultrasound has been used to evaluate a wide range of perioperative pulmonary complications and monitor changes in lung ventilation during general anesthesia. Lung ultrasound scoring and monitoring can detect early postoperative pulmonary complications after major abdominal surgery [24]. Compared with chest X-ray and clinical examination, lung ultrasound has better detection performance for respiratory complications (atelectasis, consolidation, interstitial syndrome, pleural effusion, and pneumorax after cardiac and thoracic surgery [25,26]. Lung ultrasound has a high diagnostic accuracy of 97.2% for atelectasis, 96.7% for pneumothorax, and 95.1% for pleural effusion, with good consistency with chest CT scans. It is an effective tool for evaluating perioperative pulmonary complications [27,28]. The results of this study show that lung re-expansion can reduce the occurrence of lung ultrasound scoring and atelectasis after laparoscopic gynecological surgery, improve respiratory system mechanics and oxygenation function, and the lung protective effect persists after extubation.

In protective ventilation strategies, low tidal volume often leads to inadequate end-expiratory lung volume, and repeated collapse and reinflation of the terminal airways result in atelectrauma and lung collapse. Evidence suggests that positive end-expiratory pressure (PEEP) alone is not effective in re-expanding collapsed lungs. High levels of PEEP after lung recruitment increase gas exchange in lung units and limit the impact on hemodynamics. However, the elastic recoil of the chest wall can compress and reduce the ventilated lung units, so lung recruitment should be performed every hour. The steep Trendelenburg position after pneumoperitoneum exacerbates its effects on the body, although no statistically significant changes were observed, possibly due to insufficient precision in our observation measurements. Early and sequential lung recruitment is beneficial for ventilation in gynecological surgery under laparoscopy.

Although lung ultrasound (LUS) assessment in this study may be faster, more accurate, and reliable for evaluating the postoperative lung condition compared to CT scans and bedside chest X-rays, and although optimizing PEEP after lung recruitment can reduce the incidence of postoperative LUS and atelectasis, improve respiratory mechanics, and oxygenation, it does not affect the incidence of early postoperative pulmonary complications (PPCs). This may be due to the small sample size, single disease type, and relatively young age and better respiratory function of the patients, which prevented accurate subgroup analysis, as well as the failure to observe long-term postoperative complications. The results have certain limitations, and further research is needed for final conclusions.

In conclusion. the effective combination of low tidal volume, individualized PEEP, and individualized lung recruitment methods can effectively reduce driving pressure, improve lung compliance, and respiratory function. making the protective mechanical ventilation strategy during the perioperative period more.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. [Huang]. upon reasonable request.

Declaration of competing interest

No conflict of interest exits in the submission of this manuscript. I would like to declare on behalf of my co-authors that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed. None of the authors have any personal, professional or financial conflicts of interest to declare. Research were supported by Science and Technology Plan Fund of Ma'anshan City (YL-2021-19)gram.

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Authors contribution

X.Wang and S.Cheng designed the study and conducted analyses with assistance from T.Huang. X.Wang. S.Cheng, and J.Feng wrote the manuscript. T.Huang supervised the study. All authors contributed to the final revision of the paper. All authors fully acknowledge the manuscript.

Statement

All authors fully approve the manuscript, All authors read and approved the final version of the manuscript.

Consent to participate and ethics approval

The Ethics Committee of the Third Anhui Ma'anshan 17th Metallurgical Hospital approved this clinical trial (No: XM-2021-010), we followed the Helsinki Declaration during the study. Before surgery, all patients signed informed consent forms.

Conflict of interest

All authors state they have no conflict interests.

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