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ORIGINAL RESEARCH

Effect of adjusting the positive end-expiratory pressure levels based on the driving pressure in elderly patients undergoing laparoscopic colorectal cancer surgery: a randomized controlled trial

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Abstract

A high incidence of postoperative pulmonary complications (PPCs) occurs in elderly patients due to general anesthesia. Studies show lower ventilation driving pressures may result in fewer PPCs. Appropriate levels of positive end-expiratory pressure (PEEP) may also help prevent developing PPCs in patients undergoing general anesthesia. This study aimed to test the hypothesis that driving pressure-guided PEEP titration ventilation could effectively reduce the incidence of PPCs, optimize respiratory mechanics, and improve lung oxygenation during mechanical ventilation in elderly patients undergoing laparoscopic colorectal cancer surgery. This randomized, parallel group, patient- and outcome assessor-blinded, single-center trial included a total of 70 elderly patients scheduled for laparoscopic colorectal cancer surgery. Patients were randomly divided into two groups: the titration group (receiving driving pressure-guided PEEP titration ventilation) and the control group (receiving a fixed PEEP of 5 cmH_2O). The primary endpoint was the incidence of PPCs $\geq$moderate severity within 7 days after surgery. The secondary endpoints included pulmonary oxygenation and respiratory mechanics values during surgery, post-anesthesia care unit (PACU) discharge times, and length of hospital stay. The incidence of PPCs $\geq$moderate severity within 7 days after surgery was significantly lower in the titration group (17.1%) than in the control group (45.7%) (Relative Risk (RR), 0.375; 95% Confidence Interval (CI), 0.166 to 0.845; p = 0.010). The titration group demonstrated higher dynamic lung compliance and oxygenation during mechanical ventilation than the control group. PACU discharge times and length of hospital stay were similar in both groups ($p > 0.05$). In elderly patients undergoing laparoscopic colorectal cancer surgery, driving pressure-guided PEEP titration ventilation significantly reduced the incidence of PPCs and increased dynamic lung compliance and oxygenation.

Keywords

Postoperative pulmonary complications; Positive end-expiratory pressure titration; Driving pressure; Lung protective ventilation strategies

1. Introduction

With laparoscopic colorectal cancer surgery, the trauma caused by traditional open surgery has been reduced, with benefits including minimal invasiveness, minimal intraoperative bleeding, and shorter hospital stays [1, 2]. As part of the laparoscopic procedure, the patient is usually placed in a Trendelenburg position with an artificial pneumoperitoneum established, increasing internal abdominal pressure and an upward movement of the diaphragm, which compresses the lungs and may cause atelectasis, increasing the risk of postoperative pulmonary complications (PPCs) [3, 4].

The use of small tidal volumes combined with appropriate level positive end-expiratory pressure (PEEP) ventilation and recruitment maneuvers (RMs) can reduce the incidence of PPCs and improve the prognosis for general anesthesia patients [5]. In a meta-analysis, PPCs were found to be associated with driving pressure (DP) during mechanical ventilation, but not with tidal volume [6]. Therefore, titrating individualized PEEP based on DP has become an area of research interest. In elderly patients with pulmonary degeneration or chronic diseases, PPCs are highly prevalent after general anesthesia [7]. We are not aware of studies on the effect of DP-guided PEEP titration ventilation on the incidence of PPCs in elderly patients undergoing laparoscopic colorectal cancer surgery.

We hypothesized that DP-guided PEEP titration ventilation would significantly reduce the incidence of PPCs and improve pulmonary oxygenation and respiratory mechanics during surgery in elderly patients. The study's primary endpoint was the incidence of PPCs ≥moderate severity within 7 days after surgery. Pulmonary oxygenation and respiratory mechanic variables during surgery, PPCs types, severity scores of PPCs, PACU discharge times, and length of hospital stay were considered secondary endpoints.

2. Materials and methods

2.1 General information

This was a randomized, parallel group, patient- and outcome assessor-blinded, single-center trial. A total of 70 patients were enrolled in this study who were scheduled to undergo laparoscopic colorectal cancer surgery. Inclusion criteria included 60 to 80 years of age and American Society of Anesthesiologists (ASA) physical status scores of II or III. Exclusion criteria were preoperative diseases affecting respiratory function (such as neuromuscular diseases, severe pulmonary bullae, pneumothorax and pleural effusion), chronic obstructive pulmonary disease, body mass index (BMI) ≥35 kg/m^2, uncontrolled diabetes (fasting glucose >16.7 mmol/L) or hypertension (systolic/diastolic blood pressure >180/110 mmHg), heart failure, chronic renal failure (stage 4–5 chronic kidney disease), difficult airways, mental illnesses or serious anxiety and depression, and refusal to participate.

2.2 Randomization and blinding

SPSS 22.0 statistical software (IBM Corporation, Armonk, NY, USA) was used to generate random numbers and seal them in opaque envelopes. Patients were randomized according to their envelope numbers (n = 35 per group) into titration and control groups. Intraoperative interventions and data collection were carried out by anesthesiologists aware of patient groupings. The incidence of PPCs and the severity scores were evaluated by an independent anesthetist and surgeon who were not involved in the study. Patients and investigators responsible for postoperative follow-ups and data analyses were blinded to randomization. All surgeries were performed by the same surgical group and the surgeons were unaware of the grouping.

2.3 Anesthesia

A noninvasive blood pressure measurement, continuous electrocardiogram, and pulse oximetry were routinely monitored before patients entered the operating room. We placed a radial artery catheter under local anesthesia for continuous blood pressure monitoring and intraoperative blood sample collection. After having each patient inhale 90% oxygen for preoxygenation, the anesthesiologist induced anesthesia by intravenous administration of fentanyl (2 to 4 μg·kg^{-1}), propofol (2 mg·kg^{-1}) and cis-atracurium (0.15 mg·kg^{-1}). Anesthesia was maintained with propofol (2 to 4 mg·kg^{-1}·h^{-1}), remifentanil (5 to 15 μg·kg^{-1}·min^{-1}), and sevoflurane (1% to 2% in oxygen), maintaining a bispectral index value between 40 and 60. Cis-atracurium was added to maintain muscle relaxation as necessary. When systolic blood pressure dropped below 90 mmHg or 20% of preoperative levels, vasoactive drugs (ephedrine or norepinephrine) were administered. Tropisetron (5 mg) and flurbiprofen (100 mg) were given injected 30 minutes before the end of the procedure. When patients recovered consciousness with spontaneous breathing, extubations were performed. Post-operatively, all patients were transferred to the post-anesthesia care unit (PACU). Each patient received flurbiprofen (50 mg) every 8 hours as part of their postoperative analgesia plan. Intravenous infusion began with an intravenous patient-controlled analgesia (PCA) pump containing 100 μg of sufentanil diluted with saline to a volume of 100 mL. PCA was programmed to deliver a background infusion of 2 μg·h^{-1} and bolus doses of 2 μg, with a lockout of 10 minutes and a limit of 10 μg per hour.

2.4 Intervention

In both groups of patients, we provided volume-controlled mechanical ventilation with the following initial settings: tidal volume, 6 mL·kg^{-1} (predicted body weight, PBW); fresh gas, 2 L·min^{-1}; inspiration and expiration ratios, 1:2; inspired oxygen fraction (FiO_2), 0.5; respiratory rate, 12 to 20 beats·min^{-1}; and inspiratory pause, 20%. In both groups, anesthesiologists performed recruitment maneuvers (RMs) after intubation and before extubation of patients by sustained inflation of the anesthesia reservoir bag to a peak inspiratory pressure of 35 to 40 cmH_2O for 15 s [8].

In the control group, following intubation and RMs, we set a fixed PEEP at 5 and maintained it throughout mechanical ventilation [9–11]. In the titration group, incremental PEEP titration was performed [10, 12]. After intubation and RMs, the PEEP was increased by 2 cmH_2O from 5 to 15 cmH_2O. Each PEEP was maintained for 10 breathing cycles. We recorded the plateau pressure (Pplat) and the DP (DP = Pplat − PEEP) at the last breathing cycle until the minimum DP was identified [13]. We defined the corresponding PEEP as the optimal PEEP. After establishing the pneumoperitoneum, we titrated the optimal PEEP using the same method and maintained the optimal PEEP throughout the mechanical ventilation procedures.

2.5 Data collection

Patient demographic characteristics recorded included sex, age, height, weight, BMI, smoking history, ASA physical status score, and the Assess Respiratory Risk in Surgical Patients in Catalonia (ARISCAT) score [14]. In addition, vasoactive drug utilization rates, surgery duration, pneumoperitoneum duration, amounts of colloids and crystalloids used, urine volumes, bleeding volumes, sufentanil and remifentanil dosages, tidal volumes, and PEEP values after intubation and pneumoperitoneum were recorded intraoperatively. We measured arterial blood gases 5 min after tracheal intubation (T1), 5 min after pneumoperitoneum (T2), 1 hour after the beginning of the operation (T3), and 5 min before the end of pneumoperitoneum (T4). We recorded end-tidal carbon dioxide tension ($PetCO_2$), partial pressure of arterial oxygen (PaO_2), and partial pressure of arterial carbon dioxide ($PaCO_2$). The oxygenation index (OI, OI = FiO_2/PaO_2), arterial-alveolar oxygen gradient (A-aDO_2), and dead space to tidal volume ratio (Vd/Vt, Vd/Vt = ($PaCO_2$ − $PetCO_2$)/$PaCO_2$) were calculated and recorded. We also calculated and/or recorded the peak airway pressure (Ppeak), the plateau pressure (Pplat), the DP and dynamic lung compliance (Cdyn) at T1, T2, T3 and T4. The occurrence of PPCs was adjudicated with a definition from previous studies [12, 15, 16] (Table 1). With reference to previous relevant RCT studies, we recorded the incidence of PPCs (grade 2+) within 7 days after surgery as the primary endpoint of the study [17–19]. Severity scores of PPCs, PPCs types, PACU discharge times, and length of hospital stay were also recorded.

2.6 Sample size calculation

The sample size required was estimated based on the literature indicating that the incidence of PPCs (grade 2+) are about 62% common in patients with intermediate-to-high risk [12, 20]. Assuming a relative reduction of 50% in the incidence of PPCs (grade 2+) with the use of individualized PEEP, the Power Sample Size (PASS 11.0) software program (NCSS Inc, Kaysville, UT, USA) results indicated a sample size of 32 participants per group with a type I error of 0.05 and a power of 0.80. Considering the potential losses and errors we planned to recruit 35 patients per group (by adding 10%).

2.7 Statistical analysis

We used SPSS statistical software (version 22.0, IBM, Chicago, IL, USA) to analyze all data and applied Shapiro-Wilk to determine whether the measurement data obeyed normal distribution assumptions. Normally distributed data are expressed as means ± standard deviations (mean ± SD), non-normally distributed data as medians (IQR), and categorical data as n (%). To analyze variables of sex, smoking history, ASA physical status score, incidence of PPCs within 7 days after surgery, and vasoactive drug utilization rate, we performed the chi-square or Fisher's exact tests, as appropriate. We applied the Student's *t* test to analyze mean age, height, weight, BMI, surgery duration, pneumoperitoneum duration and ARISCAT scores. The Mann-Whitney U test was used to analyze the amounts of colloids and crystalloids, urine volume, bleeding volume, sufentanil and remifentanil dosage, tidal volume, PEEP values after intubation and pneumoperitoneum, PACU discharge time and length of hospital stay. Repeated measures analysis of variance was used to analyze $PaCO_2$, OI, A-aDO_2, Vd/Vt, Ppeak, Pplat, DP and Cdyn. We considered values of $p < 0.05$ as statistically significant.

3. Results

In total, 87 elderly patients were recruited and allocated for laparoscopic colorectal cancer surgery between June 2022 and March 2023 using a CONSORT checklist (Fig. 1). 70 of the initially recruited patients were enrolled in the final analysis. Both groups showed no significant differences in characteristics ($p > 0.05$; Table 2).

Both groups showed similar surgery and pneumoperitoneum durations, amounts of colloids and crystalloids usage, urine volume, bleeding volume, sufentanil and remifentanil dosages, intraoperative tidal volume, and vasoactive drug utilization rates (all $p > 0.05$). Both PACU discharge times and length of hospital stay were similar between the two groups (both $p > 0.05$). The values of PEEP after intubation and pneumoperitoneum in the titration group were significantly higher than those in the control group (both $p < 0.001$; Table 2).

The incidence of PPCs (grade 2+) within 7 days after surgery in the titration group (17.1%) was lower than in the control group (45.7%); thus, DP-guided PEEP titration ventilation significantly reduced the incidence of PPCs (grade 2+) within 7 days after surgery (RR, 0.375; 95% CI, 0.166 to 0.845; $p = 0.010$). Compared with the control group, the incidence of PPCs (grade 2) within 7 days was significantly reduced in the titration group ($p = 0.029$), but no significant differences were observed in other grades (both $p > 0.05$). PPCs types did not differ significantly between the two groups (all $p > 0.05$) (Table 3).

Comparing the differences in patient arterial blood gas analyses between the two groups at different time points, OIs in the titration group were significantly higher than in the control group at T3 and T4 (both $p < 0.001$). A-aDO_2 values and $PaCO_2$ values in the titration group were significantly lower than in the control group at T3 and T4 (both $p < 0.001$ and both $p < 0.05$). Vd/Vt values in the titration group were significantly lower than in the control group at T4 ($p < 0.05$) (Fig. 2).

Comparing the differences in ventilatory mechanics variables between the two groups at different time points, DP in the titration group was significantly lower than control at all time points (all $p < 0.001$). Ppeak and Pplat values in the titration group were significantly higher (all $p < 0.001$). Cdyn values in the titration group were significantly higher at T2, T3 and T4 ($p < 0.001$, $p < 0.001$ and $p = 0.01$), without a significant difference at T1 ($p = 0.068$) (Fig. 3).

4. Discussion

Our study investigated the effects of DP-guided PEEP titration ventilation on elderly patients who underwent laparoscopic colorectal cancer surgery. Patients' respiratory mechanics and oxygenation during surgery improved with DP-guided PEEP titration ventilation, reducing the incidence of PPCs, which all contributed to benefiting postoperative recovery.

PPCs after anesthesia increase patients' short- and long-term mortality, and they guide clinical treatments [5, 7, 21, 22]. PPCs incidence ranges from 2% to 40% and is strongly related to preoperative risk factors, surgical approaches, and anesthesia techniques [21, 23]. PPCs (grade 2+) generally delay patients' postoperative recovery and prolong hospital stays [12], so we defined the incidence of PPCs (grade 2+) within 7 days after surgery as our primary endpoint. In general anesthesia, atelectasis is often caused by mechanical ventilation and special body positions during surgical procedures. These are important risk factors for PPCs [24]. Moreover, elderly patients suffer decreased respiratory reserve and response ability to hypoxemia, which increases their risk of postoperative PPCs [7, 21]. Therefore, for elderly patients undergoing general anesthesia, appropriate lung protective ventilation during

TABLE 1. Operational definitions of postoperative pulmonary complications.

Grade	Definition
0	No signs or symptoms
1	Cough, dry Microatelectasis: abnormal lung findings and temperature >37.5 °C without other documented cause; chest radiograph results either normal or unavailable Dyspnea, not due to other documented causes
2	Cough, productive, not due to other documented causes Bronchospasm: new wheezing or preexistent wheezing resulting in change therapy Hypoxemia: alveolar-arterial gradient >29 and symptoms of dyspnea or wheezing Atelectasis: radiological confirmation plus either temperature >37.5 °C or abnormal lung findings Hypercarbia, transient, requiring treatment, such as naloxone or increased manual or mechanical ventilation Adverse reaction to pulmonary medication
3	Pleural effusion, resulting in thoracentesis Pneumonia, suspected: radiological evidence without bacteriological confirmation Pneumonia, proved: radiological evidence and documentation of pathological organisms by Gram stain or culture Pneumothorax Reintubation postoperative or intubation, period of ventilator dependence (non-invasive or invasive ventilation) ≤48 h
4	Ventilatory failure: postoperative ventilator dependence ≥48 h, or reintubation with subsequent period of ventilator dependence ≥48 h
5	Death before discharge

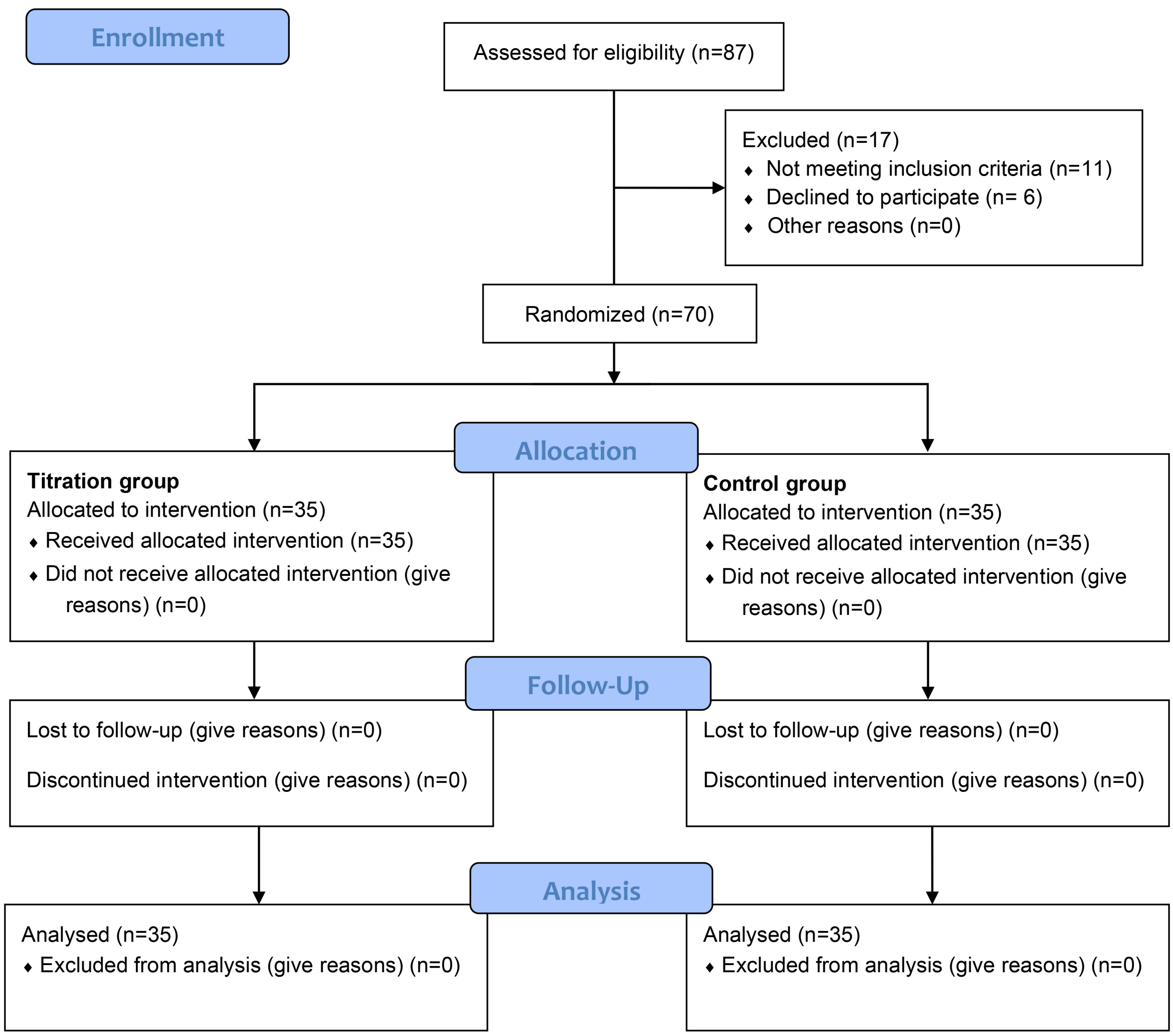

FIGURE 1. CONSORT flow diagram.

TABLE 2. Patient demographics, characteristics and surgical information.

Characteristic	Titration group	Control group	p
Sex			
Male	20 (57.1)	22 (62.9)	0.626
Female	15 (42.9)	13 (37.1)	
ASA physical status			
II	27 (77.1)	28 (80.0)	0.771
III	8 (22.9)	7 (20.0)	
Age, yr	71.4 ± 7.2	71.3 ± 6.5	0.958
Height, cm	160.6 ± 8.4	161.8 ± 6.2	0.489
Weight, kg	57.4 ± 9.3	60.0 ± 9.8	0.274
BMI, kg/m^2	22.2 ± 2.9	22.8 ± 3.0	0.391
Smoking history			
Ever smoker	14 (40.0)	12 (34.3)	0.621
Never smoker	21 (60.0)	23 (65.7)	
ARISCAT score	38.5 ± 15.7	40.1 ± 16.8	0.681
Colloids, mL	500 (500, 500)	500 (300, 500)	0.111
Crystalloids, mL	1000 (500, 1000)	1000 (500, 1000)	0.364
Urine volume, mL	300 (200, 500)	250 (200, 500)	0.276
Bleeding volume, mL	100 (100, 200)	100 (100, 200)	0.626
PEEP after intubation, cmH_2O	9 (7, 11)	5 (5, 5)	<0.001
PEEP after pneumoperitoneum, cmH_2O	15 (13, 15)	5 (5, 5)	<0.001
Duration of surgery, min	187.3 ± 63.0	170.1 ± 52.5	0.221
Duration of pneumoperitoneum, min	155.0 ± 59.5	137.3 ± 47.1	0.172
Sufentanil dosage, µg	20 (20, 30)	20 (20, 30)	0.980
Remifentanil dosage, µg	1787 (1400, 2400)	1500 (1100, 2413)	0.240
Tidal volume, mL	325 (300, 350)	350 (300, 350)	0.433
Vasoactive drug utilization rate	22 (62.9)	19 (54.3)	0.467
PACU discharge time, min	21 (15, 49)	27 (18, 35)	0.317
Length of hospital stay, days	11 (9, 16)	11 (10, 14)	0.911

Measured data with normal distribution are expressed as means ± standard deviations, Non-normally distributed data are expressed as medians (interquartile ranges). Qualitative data are expressed as n (%). PACU: Post-anesthesia care unit; ASA: American Society of Anesthesiologists; PEEP: Positive end-expiratory pressure; BMI: body mass index; ARISCAT: Asses Respiratory Risk in Surgical Patients in Catalonia.

anesthesia is crucial to ensuring rapid postoperative recovery, especially in cases of long surgical procedures. According to our results, DP-guided PEEP titration ventilation significantly reduced the incidence of PPCs (grade 2+) within 7 days of laparoscopic colorectal cancer surgery in the titration group. Comorbidities are a significant risk factor for developing PPCs [25]. Our study observed a low number of PPCs grade 3 or 4, and most were coughs and atelectasis. This may be related to the study excluding patients with serious underlying medical conditions.

Tidal volume and PEEP settings are essential for protecting the lungs during ventilation. Individualized PEEP settings can improve respiratory mechanics and reduce atelectasis [26]. As a general recommendation, the ventilator should initially be set to a PEEP of 5 cmH_2O and individualized thereafter [5]. Therefore, we started mechanical ventilation with a PEEP of 5 cmH_2O for both groups. As for the individual adjustment strategy for optimal PEEP, international consensus is lacking. DP promotes the opening of the alveoli, representing the pressure of the lung parenchyma subjected to cyclic strain during each ventilation cycle. Calculation can be achieved by subtracting the plateau pressure minus the PEEP [27]. Williams *et al.* [28] reported that DP is the only factor affecting the occurrence of PPCs, and PPCs incidence can be reduced by adjusting ventilator parameters to reduce DP. We found that PEEP in the titration group was significantly higher than in the control group. Excessive PEEPs may cause lung hyperinflation and hemodynamic fluctuations. Spadaro *et al.* [29] demonstrated that hemodynamic stability can be maintained by gradually increasing PEEP from 0 to 16 cmH_2O. Therefore, we set the

TABLE 3. Postoperative pulmonary complications.

Characteristics	Titration group	Control group	*p*
PPCs (grade 2+) within 7 days	6 (17.1)	16 (45.7)	0.010
Severity score of PPCs			
Grade 1	10 (28.6)	13 (37.1)	0.445
Grade 2	5 (14.2)	13 (37.1)	0.029
Grade 3	1 (2.9)	3 (8.6)	0.614
Grade 4	0	0	/
PPCs types			
Cough (dry or productive)	15 (42.9)	22 (62.9)	0.094
Atelectasis	9 (25.7)	15 (42.9)	0.131
Pneumonia	1 (2.9)	4 (11.4)	0.356
Bronchospasm	1 (2.9)	1 (2.9)	/
Hypoxemia	1 (2.9)	6 (17.1)	0.106

Qualitative data are expressed as n (%). PPCs: Postoperative pulmonary complications.

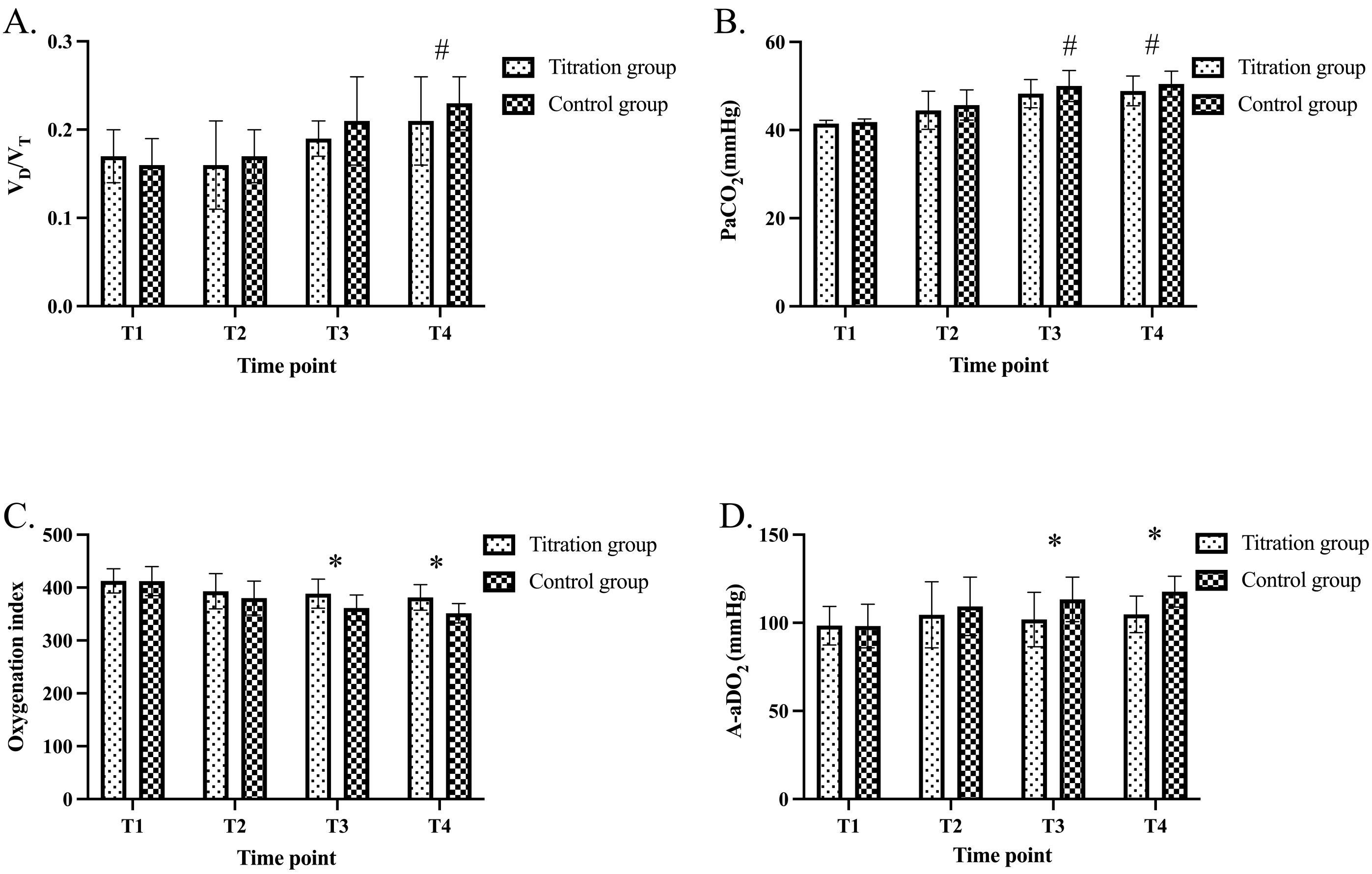

FIGURE 2. Patient arterial blood gas analyses for patients in both groups at various timepoints. (A) Dead space ventilation values; (B) $PaCO_2$ values; (C) Oxygenation index values; (D) A-aDO_2 values. $PaCO_2$: partial pressure of carbon dioxide in artery; Vd/VT: dead space to tidal volume ratio; A-aDO_2: Arterial-alveolar oxygen gradient. Data are expressed as means ± standard deviations. $^*p < 0.001$, $^\#p < 0.05$.

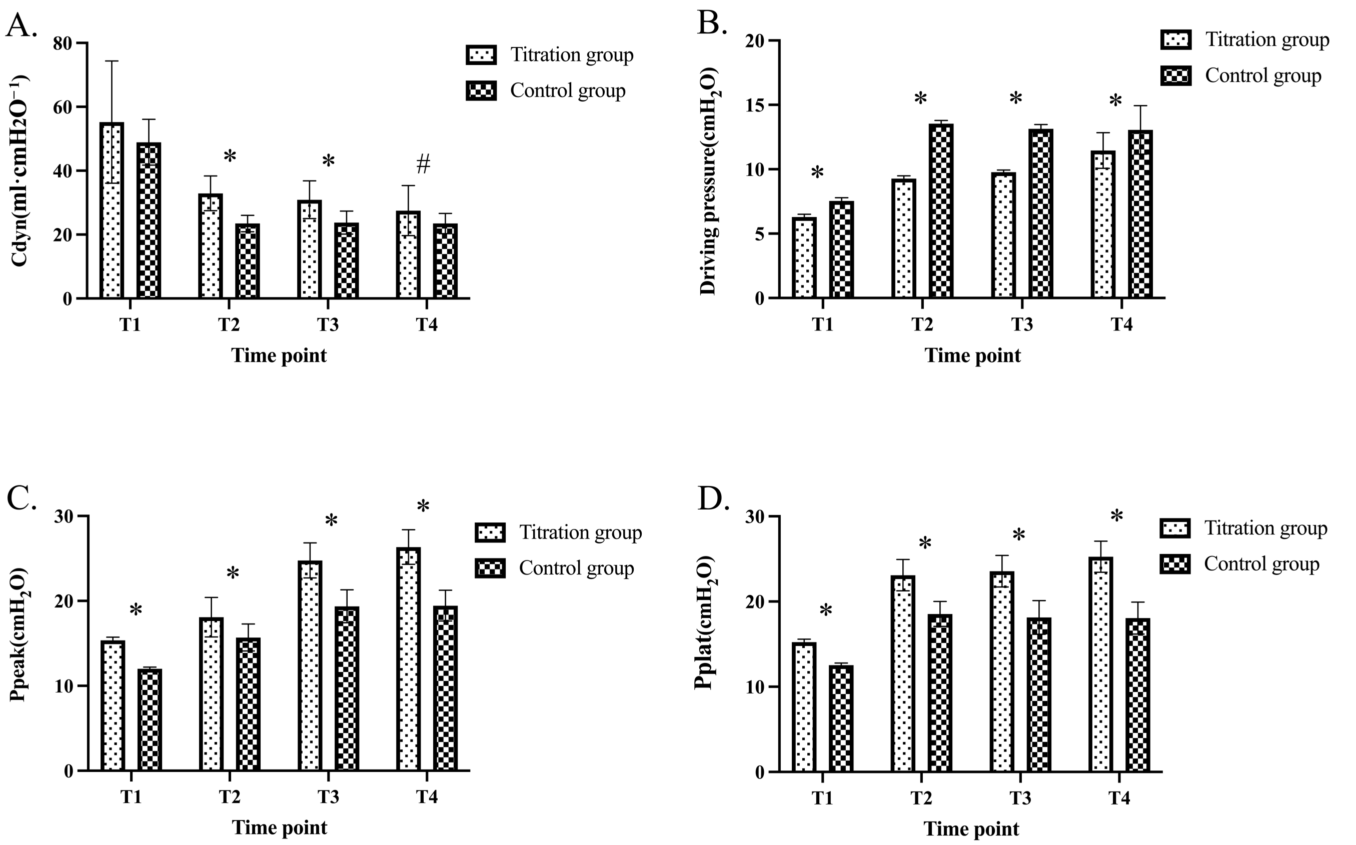

FIGURE 3. Ventilatory mechanics variables at various time points for patients in both groups. (A) Cdyn values; (B) Driving pressures; (C) Ppeak values; (D) Pplat values. Cdyn: dynamic lung compliance; Ppeak: peak of airway pressure; Pplat: plateau pressure. Data are expressed as means ± standard deviations. $^*p < 0.001$, $^{\#}p < 0.05$.

PEEP not to exceed 15 cmH_2O and observed intraoperative hemodynamic fluctuations. Both groups had similar vasoactive drug utilization rates and fluid intake and output values. Accordingly, DP-guided PEEP titration ventilation did not increase intraoperative hemodynamic fluctuations.

An increase in DP was reported to be associated with more postoperative pulmonary complications in a previous meta-analysis [6]. By using a higher PEEP guided by electrical impedance tomography, patients undergoing elective abdominal surgery experienced a decrease in postoperative atelectasis (measured by computed tomography) and an improvement in intraoperative oxygenation and driving pressures [30]. We found that intraoperative DPs in the titration group were significantly lower and PEEP was significantly higher than in the control group, whereas PPCs were significantly lower, consistent with previous studies. A decrease in Cdyn values was observed in both groups during surgery, indicating that mechanical ventilation and pneumoperitoneum damaged alveolar function. During pneumoperitoneum, the diaphragm is pushed upwards, causing atelectasis and reducing end expiratory lung volume. Cdyn values increased significantly in the titration group, possibly because PEEP effectively kept more alveoli open throughout mechanical ventilation, thereby enhancing lung compliance [30, 31]. A-aDO_2 and Vd/Vt values decreased significantly in the titration group, while OIs increased significantly at T3 and T4, showing that individualized PEEPs can improve patients' oxygenation during surgery; this improved substantially with prolonged operation time. Ppeak and Pplat values in the titration group after pneumoperitoneum were significantly higher than those in the control group. However, they remained within the normal range [32], indicating that individualized PEEP adjustments according to the DP are both safe and feasible.

Our study is limited by the following: (1) Patients over 80 or younger than 60 years old or who have serious underlying medical conditions were excluded, which limits the generalizability of the results. (2) Despite the use of a lung protective ventilation strategy, the incidence of PPCs was still high compared to previous studies, possibly due to the fact that some patients had been infected with COVID-19 within six months before surgery. However, PPCs risks in previously infected COVID-19 patients have not been published. (3) The minimum DP was set using an incremental method in this study, but further studies should assess whether diminishing the PEEPs can result in a smaller DP.

5. Conclusions

DP-guided PEEP titration ventilation alleviates PPCs incidence in elderly patients undergoing laparoscopic colorectal cancer surgery, optimizes respiratory mechanics during mechanical ventilation, and improves pulmonary oxygenation without severe adverse events. As this study was conducted in a relatively healthy elderly population, more research will be required to confirm the results in the general elderly population.

ABBREVIATIONS

ASA, American society of anesthesiologists; PACU, Post-anesthesia care unit; PPCs, Postoperative pulmonary complications; PEEP, Positive end-expiratory pressure; RMs, Recruitment maneuvers; BMI, Body mass index; PCA, Patient-controlled analgesia; FiO_2, Fraction of inspired oxygen; PBW, Predicted Body Weight; $PetCO_2$, End-tidal carbon dioxide tension; Pplat, plateau pressure; ARISCAT, Assess Respiratory Risk in Surgical Patients in Catalonia; PaO_2, Partial pressure of arterial oxygen; $PaCO_2$, Partial pressure of arterial carbon dioxide; OI, oxygenation index; A-aDO_2, arterial-alveolar oxygen gradien; Vd/Vt, dead space to tidal volume ratio; Ppeak, Peak of airway pressure; Cdyn, Dynamic lung compliance.

AVAILABILITY OF DATA AND MATERIALS

Data are available upon reasonable request. The technical appendix, statistical code and data set are available from the corresponding author.

AUTHOR CONTRIBUTIONS

LDH and YZ—designed the research study. JCX and ZHP—performed the research. QZ and YZ—analyzed the data. QZ and ZHP—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This trial was approved by the Ethics Committee of Wenzhou People's Hospital (KY-2022-053), and written informed consent was obtained from all patients. The study has been registered in the Chinese Clinical Trial Registry (ChiCTR2200061811), Registered on 03 July 2022. All participants signed consent forms.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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