Optimal Positive End-Expiratory Pressure Obtained with Titration of Fraction of Inspiratory Oxygen: A Randomized Controlled Clinical Trial

Lingling Gao

Fudan University Shanghai Cancer Center, Fudan University

Li Yang

Fudan University Shanghai Cancer Center, Fudan University

Lili Pan

Fudan University Shanghai Cancer Center, Fudan University

Yun Cui

UESTC Chengdu Women's & Children's Central Hospital

Yandong Jiang

University of Texas, Houston Health Science Center

Jun Zhang (✉ snapzhang@aliyun.com)

Fudan University Shanghai Cancer Center, Fudan University

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Abstract

Background

Optimal intraoperative positive end expiratory pressure (PEEP) improves patient outcomes. The pulse-oximetry has been used to determine the lung opening and closing pressures. Therefore, we hypothesized that intraoperative optimal PEEP obtained by titrating inspiratory oxygen fraction (FiO_2) guided with pulse-oximetry could improve perioperative oxygenation.

Methods

Forty-six males undergoing elective robotic assisted laparoscopic prostatectomy were randomly assigned to either optimal PEEP (Group O, $n=23$) or control with fixed PEEP of 5 cmH_2O (Group C, $n=23$). Optimal PEEP, defined as the PEEP with lowest FiO_2 or 0.21 to maintain $\text{SpO}_2 \geq 95\%$, was obtained in both groups after placing the patients in Trendelenburg position and peritoneal insufflation. Patients in Group O maintained the optimal PEEP and in Group C maintained PEEP of 5 cmH_2O intraoperatively. Both groups were extubated in a sitting position once the extubation criteria met. The primary outcome was the partial arterial oxygen pressure (PaO_2)/inspiratory oxygen fraction (FiO_2) prior to extubation. Secondary outcome was the incidence of postoperative hypoxemia ($\text{SpO}_2 < 92\%$ on room-air after extubation) in post-operative care unit.

Results

The median optimal PEEP was 16 $\text{cm H}_2\text{O}$ [inter-quartile range, 12-18]. The $\text{PaO}_2/\text{FiO}_2$ prior to extubation was significantly higher in Group O than that in Group C ($77.0 \pm 4.9 \text{ kPa}$ vs. $60.6 \pm 5.9 \text{ kPa}$, $p=0.04$); $\text{PaO}_2/\text{FiO}_2$ was also significantly higher in Group O 30 minutes after extubation (57.6 ± 1.9 vs. $46.6 \pm 1.8 \text{ kPa}$, $p=0.01$). The incidence of hypoxemia on room air in the post-operative care unit was significantly lower in the Group O than in the Group C (1/23, or 4.3% vs. 7/23 or 30.4%, $p=0.02$).

Conclusions

Intraoperative optimal PEEP can be achieved by titration of FiO_2 guided with SpO_2 . Maintaining intraoperative optimal PEEP improves intraoperative oxygenation and reduces the incidence of post-operative hypoxemia.

Trial registration

Background

Optimal intraoperative positive end expiratory pressure (PEEP) has been demonstrated to improve patient outcomes[1, 2]. However, the optimal PEEP is not only very different among individuals, but individual's optimal PEEP is affected by positioning, muscle paralysis, and several other factors[3, 4]. The common application of a fixed PEEP often leads to either lung overinflation or atelectasis. Therefore, optimal PEEP should be individualized and adjusted dynamically according to patients' needs[5]. Several techniques have been used to determine the optimal PEEP[6–10]. For example, electrical impedance tomography (EIT) can be performed at the bedside[5, 11, 12]. However, the application of this technique requires special training, increases the workload of the care team, and the cost-efficiency of this procedure remains to be determined. Chest CT is the gold standard technique for the assessment of lung inflation [13]. However, it is not feasible for use at the bedside, it exposes patients to X-rays, and its cost-effectiveness is not favorable. Transpulmonary pressure is another alternative that can be used at the bedside and is potentially cost-effective[14]. However, it requires special training and additional equipment in order to measure transpulmonary pressure. Lung opening or closing pressure can be used to assess and calculate intrapulmonary shunts[15]. Normally, the physiologic shunt is set at approximately 5%; if arterial blood oxygen saturation is >97% on room air, the intrapulmonary shunt is estimated to be <7%[16]. Therefore, this method can be used to assess the fraction of intrapulmonary shunts and to subsequently estimate the optimal PEEP[17, 18].

Recently, Ferrando et al. reported that optimal PEEP can be obtained via titration of PEEP by administering a minimal fraction of inspiratory oxygen (FiO_2) with the guidance of pulse oximetry (SpO_2) and measurements of transpulmonary pressure in anesthetized patients[19]. The authors found that the optimal PEEP values obtained using the two methods were comparable. Another study demonstrated that SpO_2 could be used to determine the individualized lung opening and closing pressures in patients undergoing anaesthesia and mechanical ventilation[20]. We hypothesized that optimal PEEP could be obtained by titration of intraoperative PEEP levels and FiO_2 with SpO_2 guidance. Our secondary hypothesis was that maintenance of intraoperative optimal PEEP derived via this method improves intraoperative oxygenation and reduces the incidence of postoperative hypoxemia. We tested our hypothesis in patients undergoing robotic-assisted laparoscopic prostatectomy (RALP).

Methods

Ethics

This single-centre, two-arm, parallel, randomized controlled study was approved on 19 October 2020 by the Ethics Committee of the Fudan University Shanghai Cancer Center, No.270 DongAn road, Xuhui District, Shanghai, China under the number IRB2010225-11 (Chairperson, Prof Jiong Wu) and registered in

the Chinese Clinical Trial Registry on 10 September 2021 (ChiCTR 2100051010; Principal Investigator: JZ). The study was conducted from 6 May 2021 until 10 October 2021. All patients were approached by the principal investigator and after presentation of the study purposes, written informed consent was obtained before inclusion. All methods were carried out in accordance with Declaration of Helsinki.

Inclusion and exclusion criteria

Between 6 May 2021 and 10 October 2021, adult patients aged 18 years or older who were scheduled for elective robotic-assisted laparoscopic prostatectomy under general anaesthesia and who presented with ASA physical status of I-III were recruited for this study. Patients with acute or chronic respiratory disorders, including chronic obstructive pulmonary disease (COPD), asthma, pulmonary hypertension, neuromuscular disease, and/or preoperative $\text{SpO}_2 < 95\%$ on room air were excluded. The patient enrollment process is illustrated in Fig.1.

Anaesthesia management

Patient's general demographic and medical characteristics were abstracted from medical records; the characteristics investigated herein included sex, age, body mass index (BMI), predicted body weight (PBW), ASA classification, medical history, and preoperative SpO_2 on room air. Intravenous access was established upon arrival at the operating room. Routine monitoring for general anaesthesia was performed, including ECG, noninvasive blood pressure, SpO_2 , capnography, and temperature. A radial arterial line was established in order to continuously measure arterial blood pressure and an intermittent blood draw was conducted for blood gas analysis. Patients were pre-oxygenated as usual at an O_2 flow rate of 8 l min^{-1} until their expiratory oxygen concentration reached 80% or higher. Anaesthetic induction was conducted with intravenous targeted control infusion (TCI) $4 \mu\text{g mL}^{-1}$ of propofol (Marsh mode), $0.3 \mu\text{g kg}^{-1}$ of sufentanil, and 0.6 mg kg^{-1} of rocuronium[21]. A 7.0 size tracheal tube was inserted, and correct placement was confirmed with auscultation and the presence of bilateral equal breath sounds. General anaesthesia was maintained with continuous TCI infusion of $3\text{-}4 \mu\text{g mL}^{-1}$ propofol and $1\text{-}2 \text{ ng mL}^{-1}$ remifentanil (Minto mode) as well as intermittent administration of rocuronium in order to maintain adequate muscle paralysis.

Study protocol

The study protocol is summarized in Fig.2. After tracheal intubation, mechanical ventilation was conducted with pressure-regulated volume-controlled ventilation using an operating room ventilator (Flow-i, Maquet Inc., Heidelberg, Germany). The ventilation was set at a tidal volume 6 mL kg^{-1} , was initiated with an FiO_2 of 1.0 to 0.21, a PEEP of $18 \text{ cmH}_2\text{O}$, and a respiratory rate of $12\text{-}15 \text{ beats min}^{-1}$ in order to keep the end-tidal CO_2 partial pressure between $35\text{-}45 \text{ mmHg}$. After placement in the Trendelenburg position and peritoneal insufflation, all patients received the first recruitment maneuver (RM1) of $40 \text{ cmH}_2\text{O}$ for 15 seconds followed by PEEP at $18 \text{ cmH}_2\text{O}$, similar to a previous study demonstrating that the maximal optimal PEEP was not greater than $18 \text{ cmH}_2\text{O}$ ³. If the peak

inspiratory pressure was >40 cmH₂O at a PEEP of 18 cmH₂O, the participant's study would be terminated. The target SpO₂ was 95-96%.

The PEEP titration process is shown in Supplementary Fig.1. If the SpO₂ was at 95-96% with a FiO₂ of 0.21 and a PEEP of 18 cmH₂O, the optimal PEEP was 18 cmH₂O; this was kept constant throughout the procedure until extubation. If the SpO₂ was greater than 96%, the PEEP was reduced by 2 cmH₂O step-wise, with each step lasting for 5 min until SpO₂ dropped below 95%. Then, PEEP was increased up to 18 cmH₂O in reverse order in the same stepwise manner until the intended SpO₂ was reached and remained at a steady saturation of 95-96%. At a PEEP of 18 cmH₂O, if the SpO₂ was lower than 95%, the FiO₂ was incrementally increased by 0.05 per step; each step lasted for 5 minutes in order to achieve an SpO₂ of 95-96%. If PEEP was increased to 18 cmH₂O and FiO₂ was measured at 1.0 (while the SpO₂ remained lower than 95%), the study was terminated. The PEEP level at the minimal FiO₂ necessary to maintain a SpO₂ of 95-96% was considered the optimal PEEP. Once the optimal PEEP was achieved, patients randomized to Group C received a PEEP of 5 cmH₂O intraoperatively or were maintained within Group O, thus maintaining optimal PEEP until extubation. Patients in both groups were extubated in the post anaesthesia care unit (PACU) in the sitting position once they met the criteria for extubation according to the judgment of their medical care team.

For both groups, intraoperative pulmonary dynamic compliance (C_{dyn}), PEEP, FiO₂ (i.e., real-time FiO₂ obtained from the gas analyzer within the anaesthesia machine), driving pressure, and plateau pressure were recorded continuously. Intermittent blood gas analysis was performed in order to verify the accuracy of the SpO₂ readings and to calculate the [alveolar-arterial gradient](#) [P(A-a)O₂], while the respiratory rate was adjusted in order to maintain the PaCO₂ in the range of 35–45 mmHg. In the PACU, vital signs and arterial blood gas analysis were recorded at 5, 10, and 30 minutes after extubation, and supplementary O₂ was provided to the patients via nasal cannula if the SpO₂ was below 92%.

Statistical analysis

Intraoperative PaO₂/FiO₂ was reported as 55.7 ± 10.9 kPa before extubation in patients undergoing RALP[4]; we assumed that there were 10 kPa differences between the two groups, with a variance of 10.9 kPa, a statistical power of 80%, and a two-sided α significance level of 0.05. A sample size of 18 patients in each arm was required to test our hypothesis. Considering a dropout rate of 30%, a total of 24 patients for each group (for a total of 48 patients) were enrolled; randomization was performed using a minimization randomization method as previously described[22]. Patients were stratified by age (<65 vs. ≥ 65 yrs) and BMI (<24 vs. ≥ 24 kg m⁻²) in order to test differences in age and BMI distribution. The randomization was performed via MinimPy2 software (version 2.0, OSDN, Columbus, OH, USA). Randomization was performed the day before surgery by a research team member who was blinded to the trial condition. The data were managed and analyzed by an independent researcher (PL).

Continuous variables were presented as means $\pm$ SD or medians with IQR according to whether the distribution was normal, while categorical variables were presented as counts and percentages. The χ^2 -test was used to compare differences in patient characteristics between the two groups. The unpaired t tests were used to compare differences in oxygen indices, driving pressure, and Cdyn at different time points. Repeated-measures analysis of variance (ANOVA) was used to compare differences in PaO_2/FiO_2 , driving pressure, and Cdyn under mechanical ventilation prior to extubation. Differences in vital parameters, vasoactive medication dosage, and incidence of complications were tested via unpaired t tests, and the Wilcoxon Man-Whitney test was used when the data were not normally distributed. Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) software (version 24, IBM, Armonk, NY, USA) and GraphPad Prism 8.0 software (GraphPad Inc., San Diego, CA, USA). Statistical significance was set at $P < 0.05$.

Results

Clinical characteristics

A total of 48 patients were initially enrolled in this study, though two patients were excluded from the study due to operation cancelation. Therefore, a total of 46 patients completed the study and underwent a final analysis (Fig. 1). There were no statistically significant differences between the two groups in terms of clinical characteristics (Table 1) or perioperative data (Table 2).

Optimal PEEP level

For all patients (i.e., including those in both groups) the median optimal PEEP was 16 cm H₂O (interquartile range, 12-18). The FiO_2 needed to obtain the optimal PEEP was 0.21 ± 0.03 . The details of the titration process are presented in Supplementary Table 1. The time allotted to complete the titration of the optimal PEEP was half an hour or less.

Primary outcome

The PaO_2/FiO_2 was statistically significantly higher in Group O than in Group C prior to extubation (77.0 ± 4.9 kPa vs. 60.6 ± 5.9 kPa, $P=0.04$) (Figure 3a).

Secondary outcomes

The respiratory mechanics corresponding to FiO_2 are shown in Fig.3b. There was no statistically significant difference in the driving pressure between the two groups (Fig.3c). The Cdyn was higher in Group O than in Group C (43.4 ± 2.7 ml cm H₂O⁻¹ vs. 36.5 ± 3.4 ml cm H₂O⁻¹, $P=0.032$) prior to extubation (Fig.3d). Intraoperative respiratory parameters and PaO_2/FiO_2 during PEEP intervention are shown in Supplementary Table 2.

Postoperative hypoxemia was defined as postoperative hypoxemia if $\text{SpO}_2 < 92\%$ was detected in room air within 30 min after extubation in the PACU. The incidence of hypoxemia was statistically significantly lower in Group O as compared to Group C (1/23 or 4.3% vs. 7/23 or 30.4%, $P=0.02$) (Table 2). The $\text{P(A-a)}\text{O}_2$ in Group C (9.0 ± 2.0 kPa) was statistically significantly higher than that in Group O (3.62 ± 0.9 kPa, $P=0.01$). $\text{PaO}_2/\text{FiO}_2$ ratios at three time points in the PACU after extubation are shown in Supplementary Figure 2.

Discussion

The main findings of this study are as follows: (1) intraoperative optimal PEEP can be achieved by titration of PEEP and FiO_2 guided by the SpO_2 readout in patients likely requiring high PEEP; (2) maintaining optimal PEEP improves intraoperative oxygenation and reduces FiO_2 to maintain normoxemia; and (3) the benefit of intraoperative optimal PEEP remains postoperatively in terms of reductions in the incidence of postoperative hypoxemia.

Our results confirmed the observations from a previous study[4] demonstrating that using equipment for routine anaesthesia care can obtain optimal PEEP. This technique has the substantial advantage of being simple to use. In this study, titration of PEEP and FiO_2 were started simultaneously as the surgery progressed. Therefore, clinicians were able to obtain individualized optimal PEEP levels without interrupting or prolonging the surgery. This technique does not require additional training or equipment such as an intra-esophageal balloon to calculate transpulmonary pressure[23] or electric impedance tomography to measure lung aeration[9, 24]. All the equipment needed to obtain and maintain the optimal PEEP is readily available in any modern operating room or anaesthesia site. In addition, PEEP can be constantly reassessed and adjusted intraoperatively in order to maintain the optimal PEEP when respiratory mechanics change due to changes in the patient's position or intra-abdominal insufflation pressure. A new algorithm may be developed using a closed-loop system to assess PEEP and automatically implicate the individual's optimal PEEP using this technique.

We tested our hypothesis in patients who underwent RALP because this population is more likely to require high PEEP to minimize intraoperative atelectasis[25]. The surgery was performed within the pneumoperitoneum with an intra-abdominal pressure of approximately 15 mmHg, and the patient was placed in a steep Trendelenburg position (approximately 30 degrees) intraoperatively for over 3-4 hours[26, 27]. Therefore, patients are more prone to perioperative atelectasis formation if the PEEP is not high enough to counteract the reduction in functional residual capacity[28]. However, in our institute, a PEEP of 5 cmH_2O for patients undergoing robotic-assisted laparoscopic prostatectomy is a common practice. There are a few recommendations stating that the PEEP should be higher than 5 cmH_2O if the patient is in the Trendelenburg position and/or if there is pneumoperitoneum[29]. A PEEP of 5 cmH_2O seems to be lower than that reported in the literature. However, guidelines for selecting PEEP for this patient population are unavailable due to insufficient literature informing these criteria. Any fixed PEEP would render some patients either below and above the optimal PEEP as the variation in optimal PEEP is large[4], and optimal PEEP is likely not a constant but rather varies depending on the patient's physiology

and positioning as well as the specific surgical intervention[30]. The range of optimal PEEP observed in this study ranged between 2 and 18 cmH₂O. We encountered a patient who was able to maintain a SpO₂>95% with a FiO₂ of 0.21, even when the PEEP was set at 2 cmH₂O. We also performed arterial blood gas analysis and confirmed that the SpO₂ and arterial hemoglobin oxygen saturation readouts were comparable. This indicates that, even with pneumoperitoneum and in the steep Trendelenburg position, this patient had an intrapulmonary shunt of less than 10% with a PEEP of 2 cmH₂O [16].

A question remains as to whether the optimal PEEP we obtained was truly the optimal PEEP, since we did not have access to validation via a chest CT scan or electric impedance tomography. However, though this is a scientifically important question, but it may not be clinically important. Specifically, the approach employed in this study may not achieve a true PEEP (with no over- or under-PEEP). However, the oxygenation index improved by 27% (77.0/60.6 kPa) in Group O vs. Group C prior to extubation. Further studies are needed to determine the efficacy of this technique for achieving true optimal PEEP versus that obtained with EIT. Nevertheless, using this technique, we could achieve clinically relevant improvements in intraoperative oxygenation as compared with routine care. The mean FiO₂ used to achieve optimal PEEP was 0.21, the SpO₂ was 95%-96% prior to extubation, and the intrapulmonary shunt was estimated to be <10% (as compared with that of the control group). Because we chose to titrate the optimal PEEP stepwise and bidirectionally, we were unlikely to inflate the lung at the optimal PEEP level. Therefore, even though the optimal PEEP in the present study may not be a true optimal PEEP, it is likely very close to the true optimal PEEP and the difference between the two may not have clinical implications. Further studies are needed to assess the agreement of optimal PEEP obtained with the method used in this study as well as other well-established techniques, such as CT scans or EIT.

It is important to note that we found that the benefit of intraoperative optimal PEEP is sustained postoperatively. This is consistent with previous observations suggesting that intraoperatively individualized PEEP can reduce postoperative atelectasis[2]. However, a recent study[31] showed that intraoperative PEEP only improves intraoperative, but not postoperative, oxygenation. This discrepancy among studies, including our current study, maybe due to the different extubation approaches employed in the investigations. It is well known that a patient's functional residual capacity (FRC) depends on sedation level, muscle tone, and position[32]. In our institution, it is routine practice for patients to be extubated in a sitting position. We observed the benefit of intraoperative PEEP on postoperative oxygenation when all patients were extubated in the sitting position. Therefore, patients likely maintain a larger FRC (i.e., closer to the normal value) than that of patients extubated in the supine position. This notion requires further validation. However, in a report by Simon et al., the position of the patients during extubation was not stated[31]. In our study, because there were no statistically significant differences between the two groups in terms of the consumption of intraoperative and postoperative narcotic and residual sedation levels in the PACU, the reduction in the incidence of postoperative hypoxemia in room air in Group O was likely due to a reduction in postoperative atelectasis. Since the sample size was relatively small, we could not determine the effect of intraoperative PEEP on other outcomes, such as the incidence of reintubation and postoperative pneumonia. Nevertheless, the intrapulmonary shunt in these

patients was an important factor. This is because we chose an SpO₂ of 92% or lower as the cutoff for the diagnosis of hypoxemia on room air; if we assume that the hypoxemia was due to the intrapulmonary shunt only and that no hypoxic vasoconstriction was involved, at an SpO₂ of 92%, the intrapulmonary shunt was estimated to be approximately 24% using the equation described previously[16]. Further studies should be conducted to assess the effect of intraoperative optimal PEEP on outcomes.

In addition to the substantial strengths of this investigation, this study had several limitations. First, we did not validate our observation that the optimal PEEP achieved with this technique is indeed the true optimal PEEP. Validation using EIT or transpulmonary pressure will be important for assessing the sensitivity and specificity of this method. Second, the inaccuracy of pulse oximetry for reporting hemoglobin oxygen saturation was recently determined by the FDA. However, in this study, we validated SpO₂ readings using arterial blood gas analysis. In addition, we used the same brand of oximetry in both groups of patients. Therefore, this potential inaccuracy does not affect our conclusions. Third, it is possible that the PEEP obtained in our study is above the true optimal PEEP. However, we allowed for the descending and ascending stepwise titration of FiO₂ and PEEP. Therefore, over- and under-PEEP at the level that would affect outcomes are possible, but unlikely. Though we may not achieve a perfectly individualized optimal PEEP, but in practical terms, the PEEP value achieved in our study is likely close to the true value when the intrapulmonary shunt is less than 10%.

Conclusion

In conclusion, individualized optimal PEEP can be achieved with equipment available for anaesthesia by titration of PEEP and FiO₂ guided by SpO₂. Maintaining intraoperative optimal PEEP improves intraoperative oxygenation and reduces the incidence of postoperative hypoxemia in patients likely to require high intraoperative PEEP. Since the method we used in this study to obtain optimal PEEP, this approach is practical and hopefully clinicians are willing to adopt it and improve the quality of care.

List Of Abbreviations

PEEP: positive end expiratory pressure; FiO₂: inspiratory oxygen fraction; PaO₂: partial arterial oxygen pressure; EIT: electrical impedance tomography; SPO₂: pulse oximetry; RALP: robotic-assisted laparoscopic prostatectomy; COPD: chronic obstructive pulmonary disease; BMI: body mass index; PBW: predicted body weight; TCI: targeted control infusion; RM: recruitment maneuver; PACU: post anaesthesia care unit; Cdyn: dynamic compliance; FRC: functional residual capacity

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Fudan University Shanghai Cancer Center, with the ethics number IRB2010225-11. The patients provided written consent. All methods were carried out in

accordance with Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interest: Dr. Yandong Jiang is a consultant of Vyaire, which was not involved in the design, conduct or publication of this work. The other authors declare no conflicts of interest.

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Authors' contributions

LLG conducted data analysis and manuscript preparation, drafted and finalized the manuscript; LY participated in study design, data analysis and manuscript preparation. LLP participated in protocol optimization, data retrieval and data analysis. YC participated in protocol optimization and manuscript preparation. YDJ participated in study design, data analysis, drafted and edited the manuscript. JZ participated study design, data collection and analysis, manuscript preparation and finalization.

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Tables

Table 1. Patient clinical characteristics

Characteristic	Group C (n=23)	Group O (n=23)	<i>p</i> value
Age(years)			0.55
≤65	10(43.5)	8(34.8)	
≥65	13(56.5)	15(65.2)	
BMI (kg/m²)			0.77
≤24	12(52.2)	13(56.5)	
≥24	11(47.8)	10(43.5)	
ASA physical status			
I	2(8.7)	3(13.0)	1.00
II	21(91.3)	20(87.0)	
Smoking status			
Never	15(65.3)	14(60.9)	0.13
Ever	3(13.0)	4(17.4)	
Current	5(21.7)	5(21.7)	
Comorbidity			
Hypertension	8 (34.8)	6 (26.1)	0.75
Diabetes	3(13.0)	4(17.4)	1.00

Note: Data are presented as numbers (%). Group C, control group with fixed PEEP of 5cmH₂O; Group O, optimized PEEP group with individualized PEEP at which SpO₂ is maintained at 95-96% with minimal FiO₂; BMI, body mass index; ASA, American Society of Anesthesiologists.

Table 2. Intraoperative data

	Group C(n=23)	Group O (n=23)	<i>p</i> value
Anesthesia duration (min)	227.3±7.8	218.7±5.6	0.38
Surgery duration(min)	169.1±6.4	174.1±4.2	0.47
Total amount of fluid infusion (ml)	2070±56.7	1904±68.4	0.07
Blood loss(ml)	118.7±10.0	97.8±5.9	0.08
Urinary output (ml)	347.8±37.7	358.7±51.7	0.87
Vasoactive injections			
Received medication, n (%)	21(91.3)	22(95.7)	0.55
Ephedrine (mg)	6.8±1.0	7.2±1.2	0.80
Phenylephrine (µg)	194.8±44.9	183.0±52.0	0.87
P(A-a) O ₂ pre-extubation(kPa)	9.0±2.0	3.62±0.9	0.01
SpO ₂ ≥92% at PACU on room air, n(%)	7(30.4)	1(4.3)	0.02

Note: Data are presented as mean ± SD or numbers (%); P(A-a)O₂: alveolar-arterial gradient; PACU: post-anesthesia care unit ;pre-extubation: before extubation.

Figures

Figure 1

Flowchart of patient enrollment. PEEP, positive end expiratory pressure.

Figure 2

Experimental protocol for PEEP titration. TV, tidal volume; ETCO₂, end expiratory carbon dioxide partial pressure; SpO₂, pulse oxygen saturation; RM, recruitment maneuver; PACU, postanesthesia care unit. PEEP, positive end expiratory pressure; PaO₂, oxygen partial pressure in arterial blood; FiO₂, fraction of inspired oxygen.

Figure 3

Time course of respiratory mechanics. (a) PaO_2/FiO_2 ; (b) Time course of FiO_2 ; (c) Driving pressure; (d) C_{dyn} ; * $P < 0.05$, ** $P < 0.01$. PEEP, positive end expiratory pressure; PaO_2 , partial pressure of oxygen in arterial blood; FiO_2 , fraction of inspired oxygen; C_{dyn} , dynamic compliance.

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