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Study on the Safety of Different Pressure Artificial Pneumothorax on Endoscopic Radical Esophagectomy

Yafei Bao[1*#], Lei Zhang[2#], Liang Zhen[2], Bo Jiang[2], Chen Yang[2]

[1]Department of Thoracic Surgery, Affiliated Hospital of Yangzhou University, Yangzhou, China
[2]Department of Thoracic Surgery, The First People's Hospital of Changzhou, Changzhou, China
Email: *15255261805@163.com

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Abstract

Objective: To study the effect of different pressure artificial pneumothorax on total endoscopic radical esophagectomy during and after an operation. Methods: From 2019 to 2021, 64 patients with esophageal cancer underwent video-assisted thoracoscopic surgery in the same surgical treatment group. The pressure of CO_2 artificial pneumothorax was randomly divided into Group A (pressure 6 mmHg), Group B (pressure 8 mmHg), and Group C (pressure 10 mmHg). Heart rate (HR), mean arterial pressure (MAP), end-expiratory CO_2 partial pressure ($PETCO_2$), arterial blood pH and $PaCO_2$, operation time, intraoperative blood loss, and anesthesia resuscitation time were recorded at different time points. Observe the changes in inflammatory indexes, coagulation function, and the incidence of complications in the three groups, and statistically analyze and compare the differences among the three groups of patients. Results: Sixty-four patients with esophageal cancer were included in this clinical study. There were no significant differences in gender, age, lung function, BMI, and coagulation function among the three groups ($P > 0.05$). There were significant differences in $PETCO_2$, arterial pH, and $PaCO_2$ in T2, T3, and T4 among the three groups ($P < 0.05$). The arterial blood gas index at T5 in Group A was significantly different from that in Group C ($P < 0.05$). The time of thoracic operation in Group A was significantly longer than that in the other two groups ($P < 0.05$), and the time of tracheal intubation and extubation was earlier in Group A ($P < 0.05$). The incidence of subcutaneous emphysema, thoracic tube time, and prothrombin time in Group A was significantly different from those in Group B and C ($P < 0.05$). There were no significant differences in hospitalization days, pulmonary infection, and other complications ($P > 0.05$). Conclusion: The artificial pneumothorax with 6

*Coresponding author.
#Contributed equally to this work.

mmHg pressure and 8 L/min flow rate can satisfy the operation, and its safety and postoperative recovery are also better.

Keywords

Esophageal Cancer, Minimally Invasive Surgery, Single Lumen Tracheal Intubation, Artificial Pneumothorax

1. Introduction

Esophageal cancer is a common malignant tumor of the digestive system, which has high morbidity and mortality [1]. It is often related to smoking, long-term heavy drinking, and chronic esophageal mucosal inflammation, and tends to occur in middle-aged and elderly people [2]. At present, surgical resection is still the main treatment for esophageal cancer. Including Mckeown's, Ivor Lewis's, and Sweet's. Traditional open surgery for esophageal cancer (such as McKeown's operation) often takes a 20 cm long incision between the fifth costal space of the right chest, which has large trauma and many complications, especially the pain of the incision after operation [3] [4]. After sufficient analgesia, it still affects the cough and expectoration of patients, and increases the recurrence of lung infection and anastomotic leakage. With the development of endoscopic technology, thoracoscopic, mediastinoscopic radical esophagectomy and Da Vinci robot-assisted radical esophagectomy have emerged. The surgical method of single lumen tube + artificial pneumothorax is simple and convenient for anesthesia intubation, It can make the lung fast collapse and facilitate the exposure and dissection of lymph nodes, especially the dissection of lymph nodes beside the recurrent laryngeal nerve [5], reduce the damage of energy instruments to the recurrent laryngeal nerve during the operation. The damage of thoracoscopic esophageal cancer surgery to the diaphragm is also less than that of open surgery, which has less influence on cough function of patients and is beneficial to the protection of lung function of patients [6], conducive to the postoperative recovery of patients and conforms to the concept of rapid rehabilitation.

However, artificial pneumothorax also has certain risks during operation. Artificial pneumothorax will lead to increased airway pressure, mediastinal displacement, and diaphragm downward movement. Artificial pneumothorax with higher pressure carbon dioxide can also cause unstable circulation, and CO_2 absorption by patients will also increase the risk of hypercapnia. It has been studied that in general anesthesia with bronchial blocker, maintaining the flow rate at 5 L/min and maintaining the pressure at 6 - 8 mmHg can meet the needs of thoracoscopic esophageal cancer surgery, and the arterial blood gas during operation is more satisfactory. For the method of double-lumen endotracheal intubation combined with artificial pneumothorax, it has been suggested that it is more reasonable to maintain CO_2 pressure at 6 mmHg, and as long as oxygen saturation monitoring is normal during thoracic surgery for esophageal cancer, the maximum $PaCO_2$ and the minimum pH value are 7.2 [7]. The atrophy of the right lung in single-lumen endotracheal intubation depends entirely on the positive pressure of carbon dioxide injection, so whether the carbon dioxide pressure of 6 - 8 mmHg and the flow rate of 5 L/min can meet the surgical needs further discussion. This study observed three groups of patients under different pressures of CO_2 artificial pneumothorax during and after the related indicators, reported as follows.

2. Methods and Clinical Data

From 2019 to 2021, the same surgeon performed total endoscopic esophageal cancer surgery in The First people's Hospital of Changzhou. After signing the informed consent before surgery, thoracoscopic combined with laparoscopic radical esophageal cancer surgery was performed. Inclusion criteria: 1) Neoadjuvant radiotherapy, chemotherapy, and immunotherapy were not performed before surgery. 2) Heart, liver, kidney, and lung function are normal, there is no serious basic disease, and it can tolerate thoracotomy. 3) No long-term history of heavy smoking or has given up smoking for at least two weeks. 4) Preoperative CT or PET-CT showed that there was no distant metastasis, peripheral tissue invasion, neck or supraclavicular lymph node metastasis, and non-T4 patients. 5) No drugs affecting coagulation function were used before operation. Radial artery puncture catheterization before surgery, Propofol 2 mg/kg, and sufentanil 0.15 μg/kg were used for anesthesia induction during the operation. After falling asleep, propofol 5 mg/(kg·h) and remifentanil 0.05 μg/(kg·h) were used for maintenance, and cis-atracurium 0.1 mg/(kg·h) was used for muscle relaxant. After successful anesthesia, a single-lumen tube was inserted, and the respiration was controlled by volumetric positive pressure ventilation mode. The tidal volume was 350 ml, the respiratory rate was 18 beats/min, the respiratory ratio was 1:2, and the oxygen concentration was 100%. If arterial blood carbon dioxide partial pressure is greater than 67 mmHg or pH value is less than 7.2 during operation, the tidal volume will increase. The patients were randomly divided into Group A (pressure 6 mmHg, flow 8 L/min), Group B (pressure 8 mmHg, flow 8 L/min), and Group C (pressure 10 mmHg, flow 8 L/min) according to different pressures of CO_2 artificial pneumothorax. The flow rate of the artificial pneumoperitoneum was 20 L/min and the pressure was 12 mmHg during the abdominal operation. Exclusion criteria 1) Low intraoperative pressure affects the operation field and operation to increase the pressure of artificial pneumothorax. 2) During the operation, the blood pressure and heart rate of patients decreased obviously, or the partial pressure of carbon dioxide in arterial blood gas was higher than 67 mmHg or the pH was less than 7.2, and the pressure of artificial pneumothorax should be lowered. 3) Conversion to open surgery caused by dense adhesion of thoracic cavity and abdominal cavity or other reasons. 4) Failure to extubate two hours after the operation. The relevant research has been approved by the Hospital Ethics Committee.

Patient's sex, age and tumor size, Smoking history, surgical history of the disease, body mass index (BMI), lung function were collected in the hospital, vital signs during operation, operation time, double lung ventilation (T1) after successful anesthesia, arterial blood gas analysis at 30 min (T2), 60 min (T3) after artificial pneumothorax pressure reached the standard, artificial pneumothorax closed (T4), end of the operation (T5) and the first day after the operation (T6). The number of lymph node dissection groups, blood loss, anesthesia extubation time, resuscitation time, postoperative recovery, and complications.

3. Statistical Method

IBM SPSS Statistics 21.0 software was used for statistical analysis, and prism software was used for drawing. The counting data were expressed by n, the measurement data by mean ± standard deviation, the comparison between groups was carried out by one-way ANOVA and multiple comparisons, and the classification variables were carried out by chi-square test. $P < 0.05$ was considered to be statistically significant

4. Results

From 2019 to 2021, a total of 72 patients undergoing thoracoscopic esophageal cancer surgery were collected, including 2 cases with artificial pneumothorax pressure due to low intraoperative pressure affecting the visual field of operation, 4 cases with difficulty in controlling and opening under thoracoscope due to tight adhesion of chest and abdominal cavity and intraoperative bleeding, and 2 cases with tracheal intubation returning to intensive care unit due to unsuccessful extubation after the operation. The other 64 patients successfully completed the operation, including 23 patients in group A, 21 patients in group B, and 20 patients in group C. All patients recovered well and were discharged smoothly after the operation. There was no significant difference in sex, age, BMI, lung function, smoking history, preoperative prothrombin time, tumor size, and location among the three groups ($P > 0.05$), but there was a difference in partial prothrombin time among the three groups ($P < 0.05$). See **Table 1** for details.

There was no significant difference in heart rate among the three groups at each monitoring point. About MAP: There was no significant difference among the three groups at the T1 time point. T2, T3, and T4 time points in Group C were significantly higher than those in Group A and B ($P < 0.05$). There was no significant difference in pH and $PaCO_2$ at T1 and T6, but a significant difference in T2, T3, T4, and T5 ($P < 0.05$). The higher the pressure of artificial pneumothorax, the lower pH, the higher $PaCO_2$ and $PETCO_2$. With the operation, PH gradually decreased, $PaCO_2$ and $PETCO_2$ gradually increased, and gradually returned to normal after the thoracic operation (**Table 2**, **Figure 1**, **Figure 2**).

There was no significant difference among the three groups in total operation time, number of lymph node dissection groups, blood loss during thoracic surgery, anesthesia resuscitation time, postoperative leukocyte content, and complications. There was no significant difference in the time of chest surgery between Group B and Group C, but shorter than that of Group A (P = 0.002). There were significant differences in C-reactive protein content and prothrombin time between Group A and Group C after the operation (P < 0.05), but there was no significant difference compared with Group B (**Table 3**) (**Figures 3-5**).

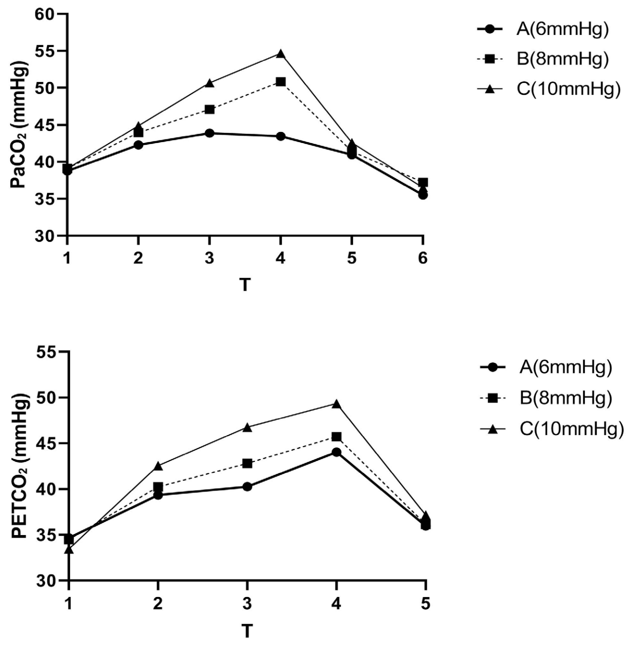

Figure 1. The change of $PaCO_2$ and $PETCO_2$.

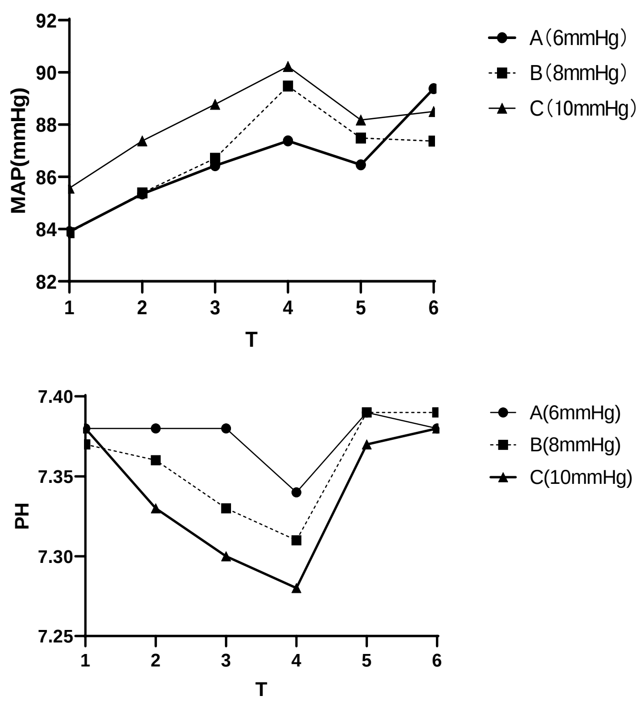

Figure 2. The change of MAP and PH.

Table 1. Characteristic of patients.

	A (n = 23)	B (n = 21)	C (n = 20)	P
Sex				
Male	16	18	18	0.19
Female	7	3	2	
Age	63.87 ± 7.70	67.76 ± 4.69	63.55 ± 7.42	0.08
BMI	23.18 ± 2.63	23.98 ± 3.04	24.02 ± 3.53	0.59
Smoking history				
Yes	12	15	13	0.40
No	11	6	7	
FEV1 (L)	2.43 ± 0.69	2.49 ± 0.55	2.42 ± 0.78	0.93
FVC (L)	2.95 ± 0.76	2.97 ± 0.69	2.92 ± 0.87	0.98
FEV1/FVC	0.79 ± 0.16	23.98 ± 3.04	0.82 ± 0.12	0.35
DLCO	22.65 ± 7.49	22.17 ± 5.66	26.41 ± 10.73	0.19
PT	11.42 ± 0.68	11.84 ± 0.47	11.52 ± 0.79	0.103
APTT	26.28 ± 1.96	27.97 ± 1.76	27.69 ± 1.60	<0.05
Tumor diameter (cm)	2.50 ± 0.67	2.49 ± 0.65	2.38 ± 0.56	0.80
Tumor site				
Upper Throcic	2	1	0	
Middle Throcic	8	11	8	0.52
Lower Throcic	13	9	12	

Table 2. Intraoperative vital signs and arterial blood gas.

	T1	T2	T3	T4	T5	T6
HR						
A	77.61 ± 8.79	65.43 ± 6.53	66.04 ± 6.23	64.7 ± 6.13	65.39 ± 6.35	78.74 ± 6.67
B	78.85 ± 8.23	65.76 ± 6.18	64.38 ± 5.84	64.05 ± 6.09	63.1 ± 5.9	77.48 ± 7.95
C	73.9 ± 7.30	62.3 ± 5.2	62.35 ± 6.68	65.5 ± 5.92	64.75 ± 5.5	77.7 ± 7.61
MAP						
A	83.90 ± 2.42	85.35 ± 2.22	86.43 ± 1.76	87.38 ± 1.79	86.46 ± 3.67	89.38 ± 3.24
B	83.86 ± 2.24	85.39 ± 2.07	86.71 ± 1.63	89.48 ± 1.45	87.49 ± 2.02	87.37 ± 3.00
C	83.57 ± 2.22	87.38 ± 1.70	88.78 ± 1.45	90.23 ± 1.09	88.18 ± 2.48	88.50 ± 2.76
PH						
A	7.38 ± 0.02	7.38 ± 0.02	7.38 ± 0.02	7.34 ± 0.02	7.39 ± 0.03	7.38 ± 0.02
B	7.37 ± 0.02	7.36 ± 0.03	7.33 ± 0.03	7.31 ± 0.04	7.39 ± 0.03	7.39 ± 0.02
C	7.38 ± 0.02	7.33 ± 0.04	7.30 ± 0.03	7.28 ± 0.04	7.37 ± 0.02	7.38 ± 0.02
$PaCO_2$						
A	38.76 ± 1.43	42.29 ± 2.11	43.90 ± 2.69	43.46 ± 1.73	40.97 ± 1.82	35.51 ± 1.89
B	39.10 ± 1.77	43.95 ± 2.34	47.09 ± 3.37	50.84 ± 3.22	41.41 ± 1.47	37.24 ± 1.74
C	39.09 ± 1.59	44.89 ± 1.85	50.69 ± 2.57	54.69 ± 3.29	42.58 ± 1.71	36.52 ± 1.48
$PETCO_2$						
A	34.65 ± 1.67	39.35 ± 1.99	40.26 ± 1.79	44.04 ± 1.43	35.96 ± 2.25	
B	34.48 ± 1.54	40.24 ± 1.51	42.81 ± 1.91	45.71 ± 1.35	36.14 ± 2.08	
C	33.45 ± 1.64	42.55 ± 1.79	46.75 ± 1.59	49.35 ± 1.66	37.15 ± 1.59	

Table 3. Surgical information and postoperative complications.

	A	B	C	P
Time of chest surgery	110 ± 7.98	103.1 ± 9.55	101 ± 6.86	0.002
Total operation time	282.39 ± 46.46	269.76 ± 45.35	259.25 ± 39.28	0.232
Blood loss during thoracic surgery	80 ± 42.10	79.52 ± 42.01	84.5 ± 38.86	0.912
Extubation time	27.23 ± 14.23	30.90 ± 10.82	38.47 ± 13.98	0.023
Resuscitation time	55.74 ± 19.75	56.67 ± 15.10	68.20 ± 18.09	0.49
Number of dissecting lymph node	4.43 ± 0.99	4.67 ± 1.02	4.55 ± 0.89	0.73
Time of chest tube	2.48 ± 0.67	2.62 ± 0.74	2.85 ± 0.88	0.023
Postoperative hospital stay	17.17 ± 11.77	19.62 ± 14.49	15.1 ± 7.99	0.473
Leukocyte content	10.51 ± 2.19	10.58 ± 3.64	11.14 ± 3.21	0.71
C-reactive protein conten	48.97 ± 14.31	61.17 ± 24.57	65.93 ± 21.52	0.02
PT	12.77 ± 0.81	13.26 ± 0.77	13.54 ± 1.35	0.042
APTT	26.14 ± 6.43	27.75 ± 2.98	27.77 ± 2.36	0.38
Lung infection				
Yes	3	3	5	0.79
No	20	18	15	
Pneumoderm				
Yes	4	7	11	0.036
No	19	14	9	
Other complications				
Yes	7	10	5	0.28
No	16	11	15	

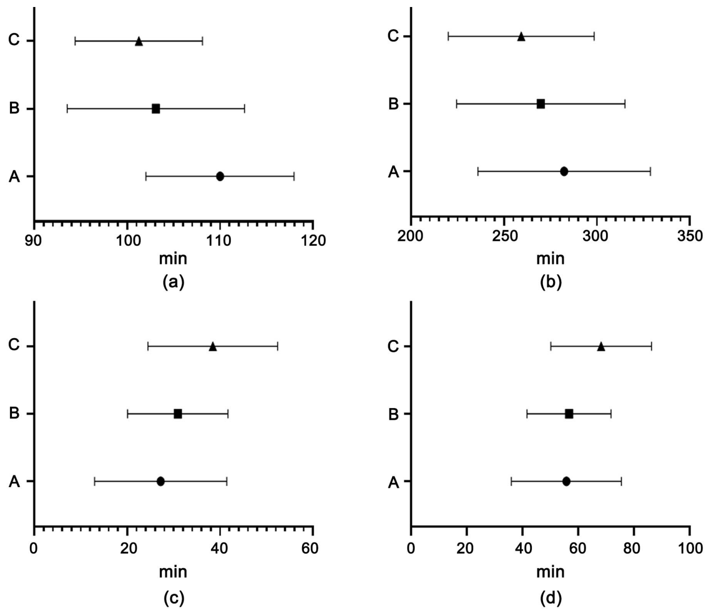

Figure 3. Surgical information of patients in three groups. (a): Comparison of chest operation time among three groups, Group A was significantly longer than group B and C (P < 0.05); (b): There was no significant difference in total operation time among the three groups (P > 0.05); (c): Postoperative extubation time of patients in three groups, group A was earlier than group C (P < 0.05); (d): Anesthesia recovery time of patients in three groups, Anesthesia recovery time was longer in group C, but there was no significant difference between the three groups (P > 0.05).

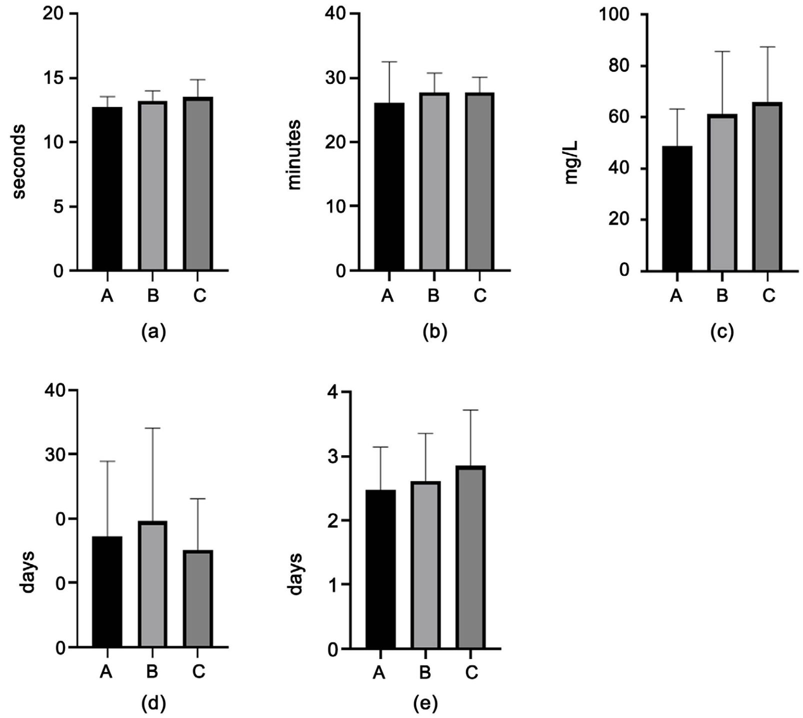

Figure 4. Postoperative recovery of patients in the three groups. (a)*: About PT, group C was longer than that of group A ($P < 0.05$); (b): There was no significant difference in APTT ($P > 0.05$); (c)*: The content of postoperative C-reactive protein in group A was lower than that in group B and C, and significantly different from that in group C ($P = 0.02$); (d): There was no significant difference in postoperative hospital stay ($P = 0.47$); (e)*: Time of chest tube, The time of group A was earlier than that of group B and C, and the difference between group A and group C was significant ($P = 0.02$).

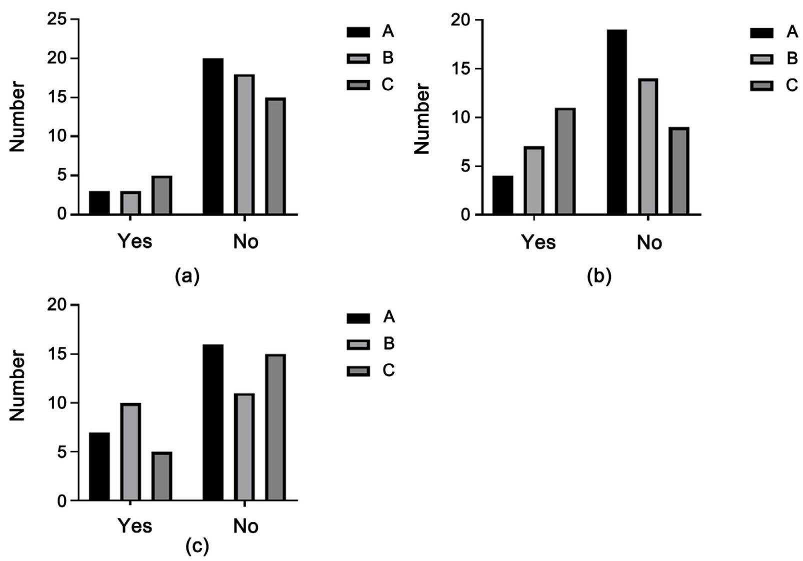

Figure 5. Incidence of postoperative complications. (a): There was no significant difference in postoperative pulmonary infection among the three groups ($P = 0.79$); (b)*: About pneumoderm, group A was significantly lower than group B and C ($P < 0.05$); (c): About other complications, there were no significant differences among the three groups ($P > 0.05$).

5. Discussion

In thoracoscopic radical esophagectomy, we found that the establishment of CO_2 artificial pneumothorax can not cause lung collapse quickly, and the effect of lung collapse often appears gradually 10 minutes after the start of artificial pneumothorax. There are two stages in the mechanism of lung collapse. The first is the active collapse mediated by the inherent elastic retraction force of the lung. Then, due to the gradual closure of the small airway in the lung, the residual gas in the alveoli is absorbed by the capillaries in the lung [8]. At low-pressure CO_2 (5 mmHg), the rate of lung collapse was not faster than that of active lung collapse, However, filling high-pressure CO_2 (>10 mmHg) has a significant inhibition on circulatory function, and the rapid high pressure in the thoracic cavity will lead to the decrease of pulmonary blood flow and delay the absorption of residual gas in alveoli. Moreover, due to the closure of small airways, the methods of increasing exhaust such as increasing intrathoracic pressure or sucking the airway with negative pressure have no obvious effect on lung collapse [9]. Due to the existence of CO_2 pneumothorax in the thoracic cavity on the operation side, the mediastinum shifts to the left side, and positive pressure ventilation of the ventilator also exists in the left lung, which forms artificial mediastinal swing and has a certain influence on respiratory function and circulatory function. Because of the pressure in the thoracic cavity on the operation side, the superior vena cava and the heart are compressed, which reduces the return blood volume of the heart and thus reduces the systolic blood pressure and diastolic blood pressure. However, the mean arterial pressure of the 10mmHg artificial pneumothorax group was higher than that of the other two groups ($P < 0.05$), and with the prolongation of the operation time, the mean arterial pressure gradually increased, but the heart rate did not change significantly, which may be because the pressure of artificial pneumothorax in the three groups had little influence on the compression of cardiac vessels. However, after the pleura absorbs CO_2, the blood $PaCO_2$ increases, and a small increase in arterial blood $PaCO_2$ can cause excitement in the respiratory center, which leads to excitement in the vasomotor center and blood pressure increase. There were significant differences in $PETCO_2$, arterial $PaCO_2$, and pH among the three groups ($P < 0.05$). The longer the thoracic operation time, the deeper the degree of respiratory acidosis, and CO_2 would be excluded from the lungs through respiration, thus increasing $PETCO_2$. $PETCO_2$, arterial blood $PaCO_2$, and pH gradually recovered after double lung ventilation. This indicates that $PaCO_2$ and pH in arterial blood are sensitive to CO_2 pressure in artificial pneumothorax. $PETCO_2$ is close to $PaCO_2$ in normal physiological conditions, and $PETCO_2$ can well reflect $PaCO_2$ in arterial blood. However, the influence of artificial pneumothorax on the internal environment reduces the correlation between them, and the reliability of $PETCO_2$ reflecting $PaCO_2$ decreases [10], so arterial blood gas analysis should be performed as much as possible to check the degree of respiratory acidosis during operation.

The time of thoracic operation, postoperative pulmonary infection, and subcutaneous emphysema were also different among the three groups ($P < 0.05$). Because the pressure of artificial pneumothorax in Group A is low, The collapse degree of the lung on the operation side is not good, Especially for the dissociation of the lower thoracic esophagus, because the existence of the heart and spine has a great influence on the surgical visual field, it is often necessary to pull the esophagus with a belt to facilitate the dissociation operation, while the artificial pneumothorax with higher pressure makes the lung collapse better, and the dissociation of the esophagus is faster, thus reducing the chest operation time. However, there is no significant difference in the total operation time among the three groups, which is mainly because the reconstruction of the digestive tract is needed in thoracoscopic esophageal cancer surgery, and the operation time is longer, thus narrowing the difference between the three groups of patients. Related studies have reported that high-pressure artificial pneumothorax can significantly increase the extubation time and anesthesia time of patients. The hemodynamic inhibitory effect caused by high intrathoracic pressure will exceed the cerebral vasodilation effect caused by hypercapnia, which shows that the decrease of cerebral perfusion affects anesthesia resuscitation. In this study, the effect of low pressure CO_2 artificial pneumothorax on postoperative anesthesia resuscitation in group A was small, and the time of tracheal intubation removal was significantly shorter than that in the other two groups ($P < 0.05$). Although the surgical method in this study is single-lumen tracheal intubation and double lung ventilation, because artificial pneumothorax on the operation side collapses the lung and reduces the ventilation function of the right lung, it mainly relies on left lung ventilation to maintain oxygen supply. During one-lung ventilation, the oxygen content in collapsed lungs decreases, and pulmonary vasoconstriction leads to the decrease of blood perfusion, which induces and aggravates the injury of pulmonary vascular endothelial cells. After resuming double-lung ventilation, lung tissue resumes blood perfusion, which causes a large amount of oxygen free radicals to be released and produces a serious oxidative stress reaction, resulting in a large number of inflammatory factors to be released [11] [12] [13]. In the study, the postoperative pulmonary infection in group A was less than that in groups B and C, and the inflammatory indexes on the first day after operation were significantly different from those in groups B and C, which indicated that low CO_2 artificial pneumothorax pressure had less damage to pulmonary vessels, and better protection for lungs and lower incidence of postoperative pulmonary complications.

There are few studies on the effect of CO_2 artificial pneumothorax on coagulation function after an esophageal cancer operation, and there is no clear conclusion. Some studies have compared minimally invasive and open laparoscopic surgery, and there is no significant difference in coagulation function between the two surgical methods [14]. Some studies have found that the coagulation function of laparoscopic patients is enhanced after the operation, which may be caused by the damage of hypercapnia to vascular endothelial cells caused by artificial pneumoperitoneum and the venous blood stasis of lower limbs caused by the high head and sole position of patients [15]. In this study, there was no significant difference in coagulation function among the three groups before operation. Compared with the three groups, prothrombin time, partial prothrombin time, and fibrinogen all increased to different degrees after the operation, suggesting that the coagulation function decreased and the fibrin volume increased after the operation. The prothrombin time in Group A was significantly lower than that in Group B and C ($P < 0.05$), which indicated that high pressure CO_2 artificial pneumothorax would increase the damage to the exogenous coagulation system and increase the risk of postoperative bleeding. However, in this study, the coagulation factors of patients after operation were not further detected, and it is not clear which coagulation factors will be damaged by artificial pneumothorax. For the comparison of partial prothrombin time, there is no significant difference among the three groups after the operation, which may be due to the lack of included data, and the partial prothrombin time itself is also different among the three groups before the operation, which makes the results of experimental analysis have large errors.

6. Conclusion

To sum up, artificial pneumothorax in thoracoscopic radical esophagectomy has a certain influence on circulatory function, especially acid-base balance in an internal environment. With the increase of pressure and the extension of the thoracic operation time, this difference becomes particularly significant. Therefore, it is more appropriate to set the pressure of artificial pneumothorax at 6 mmHg and the flow rate at 8 L/min. For individual patients with poor lung collapse, the pressure of artificial pneumothorax can be adjusted to 8 mmHg, or tidal volume can be reduced under the condition of ensuring normal oxygen saturation. Do not use artificial pneumothorax with a pressure of 10 mmHg as far as possible.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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