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Original Article

The impact of various artificial pneumothorax on the quality of surgical exposure in thoracic esophageal laparoscopic surgery

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Abstract: Objective: This study is to explore the impact of different pressure of artificial pneumothorax on surgical exposure and patients' respiratory and circulation in thoracic esophageal laparoscopic surgery. Method: The 60 esophageal cancer patients were randomly divided into 2 groups: the experiment group (single lumen endotracheal intubation with artificial pneumothorax pressure of 9 mmHg) and the control group (double lumen endotracheal intubation with artificial pneumothorax pressure of 6 mmHg), with 30 cases in each group. With low-speed inflation (2-3 L/min), invasive arterial pressure, heart rate, pulse oximetry, end-tidal CO_2 partial pressure, blood PH value, PO_2, PCO_2, and blood gas analysis was monitored before inflation, 15 min, 30 min, and 45 min of inflation, and 15 min after inflation. Surgical exposures were assessed using surgical exposure quality score sheet. Results: After CO_2 inflation, there was no obvious change in invasive blood pressure and pulse oximetry at baseline, while there were significant differences in heart rate, airway pressure, CO_2 partial pressure, end tidal CO_2 partial pressure, PH value and oxygen partial pressure between the two groups. Fifteen minutes after the inflation, all indicators returned to baseline. The changes of indicators were smaller in experiment group compared with control group. Conclusion: The surgical exposure was better and with less impact on patients' respiratory and circulation in 9 mmHg single lumen endotracheal intubation group, compared with 6 mmHg double-lumen endotracheal intubation group in thoracoscopic esophageal resection.

Keywords: Esophageal cancer, thoracoscopy, laparoscopy, CO_2, artificial pneumothorax, quality of surgical exposure

Introduction

The benefits of video-assisted thoracoscopic surgery (VATS) include less wound, quicker postoperative recovery, less complications when compared with traditional thoracotomy that have been gradually used [1] Thoracic esophageal cancer laparoscopic surgery has been used for a fairly long time in our hospital. However, compared with traditional thoracotomy, thoracoscopic surgery requires better surgical exposure. Currently selective single lung ventilation by double-lumen endotracheal intubation is most commonly used, and satisfactory surgical exposure is achieved in most cases. However, its clinical application is limited due to the following reasons: the complicated operation of double-lumen endotracheal intubation; the difficult position of double-lumen tube due to inconsistent trachea anatomy [2]; easily shifted position during the operation, causing incomplete lung collapse, difficult surgical exposure or even thoracotomy; unfit for double-lumen catheter (such as children or patients with small glottis); high expenses of double-lumen tubes compared with single-lumen tube. Artificial pneumoperitoneum is routinely used in laparoscopic surgery, and has been the current standard method [3, 4]. The CO_2 induced artificial pneumothorax method is identical with the artificial pneumoperitoneum, which is continuous CO_2 inflation with controlled flow rate; so stable positive airway pressure is formed in pleural cavity for lung collapse and surgical exposure [5]. However, there is limited study on the optimal pressure of artificial pneumoperitoneum to achieve best surgical exposure quality with minimum impact of patient's respiratory

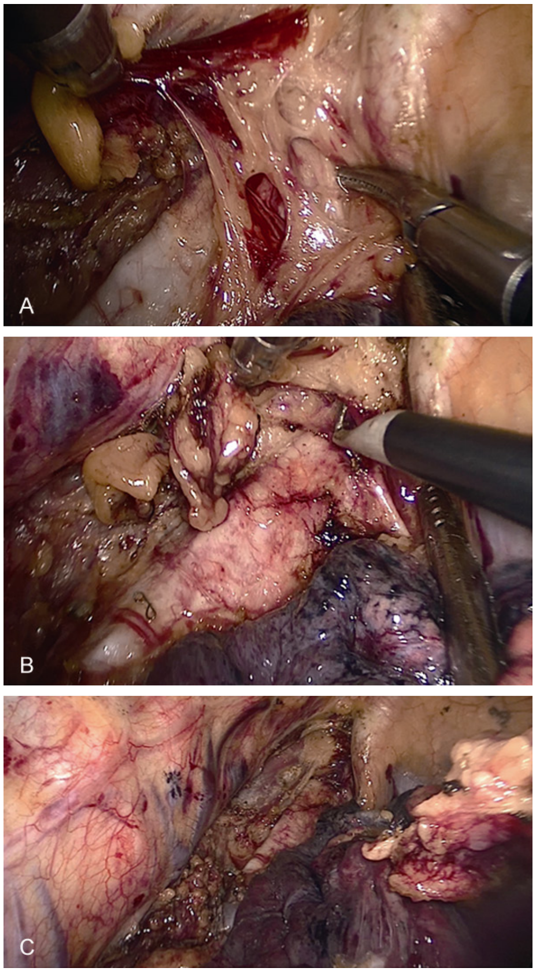

Figure 1. A-C. Dissection ofright recurrent laryngeal nerve lymph nodes.

and circulation systems. In this study, 60 cases of laparoscopic thoracic esophageal cancer were operated by single lumen endotracheal intubation (artificial pneumothorax with intrathoracic pressure of 9 mmHg) and double-lumen endotracheal intubation (artificial pneumothorax with intrathoracic pressure of 6 mmHg), and their clinical outcomes were analyzed.

Patients and methods

Subjects

From December 2013 to October 2014, 60 cases of esophageal cancer were recruited for thoracic esophageal cancer laparoscopic surgery under general anesthesia after artificial pneumothorax. The 30 cases with double-lumen endotracheal intubation and artificial pneumothorax of 6 mmHg were considered as control group, including 22 males and 8 females with age of 60.6 ± 5.5 years. The 30 cases with single lumen endotracheal intubation and artificial pneumothorax of 9 mmHg were considered as experiment group, including 21 males and 9 females with age of 62.8 ± 6.1 years. There were no significant differences of patients' age, gender, tumor staging and subtypes between the two groups ($P > 0.05$). All patients underwent endoscopy and were diagnosed as esophageal squamous cell cancer by pathology. CT showed esophageal resection and parallel lymph node dissection should be performed. Prior written and informed consent were obtained from every patient's family and the study was approved by the ethics review board of Sichuan Tumor Hospital.

Surgery methods

At first, thoracic esophagus was disassociated and chest lymph node were dissected by thoracoscopy when patients in semi-prone position. Patients' front right arm was placed around head with right side elevation of 30° in semi-prone position under general anesthesia. Thoracoscopy was placed through a 10 mm incision by the 7th intercostal space of the right axillary line for primary observation and pleural adhesion detection. Then CO_2 was injected from the trocar for artificial pneumothorax and complete lung collapse. The mediastinum was fully exposed, and electrical hook, grasping forceps and suction device were placed through 5 mm, 10 mm and 5 mm incisions on 5th, 8th midline intercostal space and 4th axillary intercostal space respectively. The right lower lung ligament was released to expose the posterior mediastinum. The mediastinal pleura were exposed for tumor detection. The bizarre vein bow was exposed using Hem-o-lock or double jaw folders with titanium ultrasound knife cutting. The esophagus was then lifted to separate the whole thoracic esophagus from neck to the diaphragmatic hiatus. The recurrent laryngeal nerve first in order to avoid injury, then left and right recurrent laryngeal nerve lymph nodes, paraesophageal lymph nodes, subcarinal lymph nodes, lymph nodes surrounding left main bronchus, and diaphragm lymph nodes were dissected as in **Figure 1A-C**. The thoracic duct was seperated from diaphragm and

Table 1. Clinical surveillance indicators of control group (double lumen endotracheal intubation with intrathoracic pressure of 6 mmHg) (n = 30)

	Before pneumothorax (T1)	15 min of CO_2 inflation (T2)	30 min of CO_2 inflation (T3)	45 min of CO_2 inflation (T4)	15 min of CO_2 inflation (T5)
Systolic blood pressure (mmHg)	116.90±13.37	118.38±12.03	116.55±12.06	119.52±14.99	117.31±11.48
Diastolic blood pressure (mmHg)	69.66±8.49	71±7.01	69.66±6.35	70.28±8.3	72.79±7.46
Heart rate (beats/min)	68.86±8.99	90.59±5.14*	96.38±4.32*	92.83±5.11*	70.93±9.79
Oxygen saturation degree (%)	99.79±0.49	99.24±0.87	99.21±1.01	98.90±1.18	99.76±0.69
Airway pressure (mmH_2o)	14.48±2.43	25.69±2.58*	26.76±3.44*	27±4.09*	14.72±2.8
PH value	7.37±0.04	7.11±0.05*	7.02±0.05*	6.97±0.06*	7.36±0.04
CO_2 partial pressure (mmHg)	37.97±3.1	53±4.96*	59.75±3.89*	59.82±3.95*	42.14±3.76
$ETCO_2$	35.41±2.72	42.38±3.29*	45.14±2.84*	45.78±3.04*	37.34±2.96
Oxygen partial pressure (mmHg)	383.21±45.31	220.17±44.25*	180.83±44.17*	170.55±43.45*	315.76±46.77

Note: Compared with before artificial pneumothorax, *$P < 0.05$ was considered as statistically significant. $ETCO_2$: End-tidal partial pressure of CO_2.

Table 2. Clinical surveillance indicators of experiment group (single lumen endotracheal intubation with intrathoracic pressure of 9 mmHg) (n = 30)

	Before pneumothorax (T1)	15 min of CO_2 inflation (T2)	30 min of CO_2 inflation (T3)	45 min of CO_2 inflation (T4)	15 min of CO_2 inflation (T5)
Systolic blood pressure (mmHg)	118.17±12.29	118.97±14.41	117.97±10.74	115.72±11.14	119.07±11.68
Diastolic blood pressure (mmHg)	66.97±8.2	68.79±11.13	64.93±9.96	65.34±11.25	66.07±9.14
Heart rate (beats/min)	75.17±11.81	87.72±9.96*	90.45±11.57*	87.28±10.43*	72.62±10.51
Oxygen saturation degree (%)	99.72±0.84	99.66±1.17	99.45±1.4	99.14±1.94	99.97±0.19
Airway pressure (mmH_2o)	14.79±3.85	24.45±4.69*	25.14±5.55*	24.97±5.29*	15.34±3.73
PH value	7.37±0.08	7.31±0.06*	7.27±0.07*	7.26±0.08*	7.35±0.07
CO_2 partial pressure (mmHg)	36.75±7.16	43.98±9.85*	47.52±12.32*	47.84±13.05*	39.32±11.1
$ETCO_2$	38.07±4.11	42.23±3.83*	44.68±3.67*	44.36±3.3*	37.04±3.59
Oxygen partial pressure (mmHg)	384±49.68	235.21±49.88*	190.1±46.99*	172.21±44.53*	326.41±42.74

Note: Compared with before artificial pneumothorax, *$P < 0.05$ was considered as statistically significant. $ETCO_2$: End-tidal partial pressure of CO_2.

clipped by conventional titanium clip to test whether trachea was injured or leaked. Thorax tube was place through 7th intercostal space and the incision was sutured.

Then the stomach was exposed to build stomach tube by laparoscopy. Patients' stomach was separated in supine position by laparoscopy with abdominal gas pressure of 14 mmHg. Left gastric artery, celiac artery trunk and splenic artery surrounding lymph nodes were dissected. Esophagus was dissected in gastroesophageal junction. Esophageal incision was sutured to remove part of the lesser curvature for stomach tube. The stomach was sutured around fundus.

The cervical esophagus was dissected around left common carotid, specimens were removed, esophagus stomach incision was sutured [6, 7].

Surveillance indicators

Systolic blood pressure, diastolic blood pressure, heart rate (HR), oxygen saturation degree (SpO_2), airway pressure (mmH_2O), PH value, O_2 partial pressure (mmHg), CO_2 partial pressure (mmHg) and end-tidal partial pressure of CO_2 ($ETCO_2$) before inflation (T1), 15 min of inflation (T2), 30 min of inflation (T3), 45 min of inflation (T4) and 15 min after inflation (T5) were compared between two groups. Dorsal artery puncture was taken to continuously monitor HR, invasive arterial blood pressure (ABP), SpO_2 and $ETCO_2$. Baseline indicators were taken before CO_2 inflation when patients were in anesthesia, and the above indicators were tested by arterial blood gas analysis.

Surgical exposure quality was assessed by the surgeon with modified Fromme Surgical

Table 3. Blood gas analysis between control group and experiment group

Time	Group	Heart rate	Airway pressure	PH value	Oxygen partial pressure	CO_2 partial pressure	$ETCO_2$
T1	Control	68.86±8.99	14.48±2.43	7.37±0.04	383.21±45.31	37.97±3.1	35.41±2.72
	Experiment	75.17±11.81	14.79±3.85	7.37±0.08	384±49.68	36.75±7.16	38.07±4.11
T2	Control	90.59±5.14	25.69±2.58	7.11±0.05	220.17±44.25	53±4.96	42.38±3.29
	Experiment	87.72±9.96	24.45±4.69	7.31±0.06*	235.21±49.88	43.98±9.85*	42.23±3.83
T3	Control	96.38±4.32	26.76±3.44	7.02±0.05	180.83±44.1	59.75±3.89	45.14±2.84
	Experiment	90.45±11.57	25.14±5.55*	7.27±0.07*	190.1±46.99	47.52±12.32*	44.68±3.67*
T4	Control	92.83±5.11	27±4.09	6.97±0.06	170.55±43.45	59.82±3.95	45.78±3.04
	Experiment	87.28±10.43	24.97±5.29*	7.26±0.08*	172.21±44.5	47.84±13.05*	44.36±3.3*
T5	Control	70.93±9.79	14.72±2.8	7.36±0.04	315.76±46.77	42.14±3.76	37.34±2.96
	Experiment	72.62±10.51	15.34±3.73	7.35±0.07	326.41±42.74	39.32±11.1*	37.04±3.59*

Experiment group: Single-lumen endotracheal intubation with intrathoracic pressure of 9 mmHg; Control group: Double-lumen endotracheal intubation with intrathoracic pressure of 6 mmHg. Comparison between control group and experiment group, *$P<0.05$ was considered as statistically significant. $ETCO_2$: End-tidal partial pressure of CO_2.

Table 4. Comparison of surgery exposure quality

Group	Surgical exposure quality (n, Grade)				
	1	2	3	4	5
Experiment	26	1	3	0	0
Control	15	11	4	0	0

Exposure Quality Score: Grade I as good exposure; Grade II as moderate exposure that can be improved by adjusting surgical instruments; Grade III as difficult exposure that needs auxiliary equipment to complete the surgery; Grade IV as poor exposure that needs repetitive incisions and auxiliary equipment; Grade V needs to change patient's position.

Statistical analysis

SPSS 17.0 softwarewas used for statistical analysis. All measurements were presented with mean ± standard deviation. Group comparison used ANOVA, and qualitative data comparison used X^2 test, with $P < 0.05$ as statistically significant.

Results

Postoperative and preoperative clinical indicator comparison

To determine safety and efficacy of CO_2 laparoscopy inflation, postoperative and preoperative clinical indicators of the 60 cases of esophageal cancer were compared. As in **Tables 1** and **2**, there was no significant difference of baseline ABP and SpO_2 between experiment and control group ($P > 0.05$). HR, airway pressure, CO_2 partial pressure and $ETCO_2$ increased in both groups compared with baseline with statistical significance ($P < 0.05$). PH value and O_2 partial pressure decreased compared with baseline with statistical significance ($P < 0.05$). However, 15 min after inflation, all indicators returned to baseline. These results indicate that though CO_2 laparoscopy inflation impacted postoperative HR, airway pressure, CO_2 partial pressure and $ETCO_2$ levels, all indicator level returned to baseline 15 min after the procedure.

Clinical indicator comparison

To determine the postoperative physiology indicator changes, group comparison was performed, as in **Table 3**. At T1, there were no significant differences of all indicators between two groups ($P > 0.05$). At T1, T2, T3, T4 and T5, there were no differences of HR and O_2 partial pressure between the two groups ($P > 0.05$). At T3 and T4, the airway pressure increase in experiment group was significantly lower than that of control group ($P < 0.05$). At T2, T3 and T4, PH value decrease in experiment group was significant lower than that of control group ($P < 0.05$). At T2, T3, T4 and T5, CO_2 partial pressure increase in the experiment group was significantly lower than that of control group ($P < 0.05$). At T3, T4 and T5, $ETCO_2$ increase in experiment group was significantly lower than that of control group ($P < 0.05$). These results indicate that postoperative physiology indicator changes were smaller in experiment group, compared with control group.

Surgical exposure quality comparison

To determine the surgical exposure quality, surgical exposure quality score was shown in **Table 4**. There were 26 cases of Grade I in experiment group, which was significantly higher than that of control group ($P < 0.05$). There were 2 cases of Grade II in experiment group, which was significantly lower than that of control group ($P < 0.05$). These results indicate that the surgical exposure quality was better in experiment group, compared with control group.

Discussion

Artificial pneumoperitoneum has been routinely used in laparoscopic surgery [3]. Therefore it should also be applied to artificial pneumothorax thoracic surgery. It is shown [8] that with low-speed inflation (2-3 L/min) and intrathoracic pressure of 6-10 mmHg, patients' HR, airway pressure and CO_2 partial pressure increased with varying degrees after CO_2 inflated artificial pneumothorax. However, all indicators remained stabilized after 30 min. Five minutes after inflation, all indicators returned to baseline. CO_2 induced artificial pneumothorax with controlled flow rate would form stable positive pressure in the pleural cavity for lung collapse and surgical exposure [5]. The manually controlled pressure of pneumothorax would affect respiratory and circulatory physiology, thus its application at present remains controversial. Studies [4, 9] have shown that CO_2 induced artificial pneumothorax can be safe and effective with chest pressure of 8-10 mmHg.

In this study, it is found that HR, airway pressure, CO_2 partial pressure, $ETCO_2$, PH value and O_2 partial pressure changed with varying degrees in both groups with statistical significance ($P < 0.05$). This is because that artificial pneumothorax can affect respiratory and circulatory physiology with varying degrees of pressure in the chest. However 15 min after inflation, all indicators returned to baseline levels. The respiratory and circulatory change was smaller in the experiment group than that of control group. Because single lumen endotracheal intubation (double lung ventilation) leads to incomplete collapse with certain ventilation, which can improve double-lumen endotracheal intubation induced hypoxemia and hypercapnia hyperlipidemia. In consistent with Huanwen Chen [5], single lumen cannula is more secure for patients, when compared with double lumen.

Moreover, it is found that the single lumen endotracheal intubation (intrathoracic pressure of 9 mmHg), compared with double-lumen (intrathoracic pressure of 6 mmHg). With CO_2 inflation, the extra CO_2 can promote surgical induced smog out of chest for clearer surgical exposure [5].

Therefore, CO_2 induced artificial pneumothorax is safe and effective in thoracic esophageal cancer laparoscopic surgery. Single-lumen endotracheal intubation (intrathoracic pressure of 9 mmHg) is safer with better surgical exposure, compared with double-lumen endotracheal intubation (intrathoracic pressure of 6 mmHg).

In addition, reduced tidal volume and increased respiratory rate can decrease mediastinal swing, which would not only improve ventilation, but also reduce its impact on patients during CO_2 inflation.

It is shown [10-12] that CO_2 induced pneumoperitoneum may promote tumor growth and metastasis, that it is recommended artificial pneumoperitoneum pressure should not exceed 14 mmHg in cancer surgery. However it is also shown that CO_2 inflation would not promote the probability of peritoneal metastasis [13]. The clinical application of artificial pneumothorax is of relatively short time, the impact of CO_2 induced pneumothorax on pleural microenvironment and the pressure on tumor metastasis still needs further exploration.

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Disclosure of conflict of interest

None.

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