Application of Right Bronchial Occlusion Under Artificial Pneumothorax in the Thoracic Phase of Minimally Invasive Mckeown Oesophagectomy

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Abstract

Background: To evaluate the feasibility and safety of single-lumen endotracheal intubation combined with right bronchial occlusion under artificial pneumothorax in minimally invasive McKeown oesophagectomy.

Methods: A total of 165 patients who underwent minimally invasive McKeown oesophagectomy at Peking Union Medical College Hospital from 2014 to 2019 were retrospectively analysed. A total of 117 patients received single-lumen endotracheal intubation combined with right bronchial occlusion (SLET-B group), and 48 patients received double-lumen endotracheal intubation (DLET group). Clinical data, intraoperative haemodynamics, surgical variables, and postoperative complications were analysed and compared.

Results: The clinical characteristics of the two groups were similar. Compared with the DLET group, a shorter intubation time and lower tube dislocation rate were found in the SLET-B group ($P < 0.05$). In the thoracic phase, with the application of artificial pneumothorax, patients in the SLET-B group had lower $PaCO_2$ and $PetCO_2$ values and higher pH ($P < 0.05$) than those in the DLET group. These parameters gradually returned to normal half an hour after the thoracic phase. Patients in the SLET-B group had shorter thoracic phase times and hospital stays and less intraoperative haemorrhage than those in the DLET group. The numbers of thoracic and bilateral recurrent laryngeal lymph nodes harvested were significantly higher in the SLET-B group.

Conclusions: Compared with double-lumen endotracheal intubation anaesthesia, single-lumen endotracheal intubation combined with right bronchial occlusion under artificial pneumothorax is feasible and safe in minimally invasive McKeown oesophagectomy. It has great advantages in surgical safety and the number of thoracic lymph nodes harvested.

Background

Oesophageal cancer is one of the most common cancers in the world (1). The pathological types are mainly divided into squamous cell carcinoma and adenocarcinoma. These two pathological types account for more than 95% of the total number of oesophageal cancers. In contrast to European and American populations, in which adenocarcinoma predominates, more than 90% of oesophageal cancer patients in China have squamous cell carcinoma. Oesophagectomy is considered to be the best therapeutic treatment for resectable oesophageal cancer. In recent years, minimally invasive oesophagectomy (MIE) has gained popularity with less trauma, morbidity and mortality than open surgery (2). In contrast to traditional double-lumen endotracheal intubation anaesthesia, single-lumen endotracheal intubation combined with right bronchial occlusion under carbon dioxide (CO_2) artificial pneumothorax is a new type of anaesthetic technology. It has less complexity of intubation, less damage to the trachea, and easier tube management. Continuous artificial pneumothorax achieves better lung collapse and surgical field exposure, which are more convenient for tumour resection and lymphadenectomy, especially for the left recurrent laryngeal nerve (RLN). This study retrospectively analysed 165 patients who underwent minimally invasive McKeown oesophagectomy at Peking Union Medical College Hospital from 2014 to 2019. We evaluated the feasibility, safety and surgical advantages of single-lumen endotracheal intubation combined with right bronchial occlusion under artificial pneumothorax compared with traditional double-lumen endotracheal intubation.

Methods

A total of 165 patients who underwent minimally invasive McKeown oesophagectomy by one major surgeon (Dr. Li) at Peking Union Medical College Hospital from 2014 to 2019 were retrospectively selected. All patients were diagnosed with oesophageal cancer by gastroscopy biopsy, and the tumour location was evaluated by upper gastrointestinal angiography and enhanced computed tomography of the chest and abdomen. Distant metastases were excluded by positron emission tomography (PET) and enhanced head nuclear magnetic resonance (MRI). One hundred seventeen patients received single-lumen endotracheal intubation combined with right bronchial occlusion under artificial pneumothorax (the SLET-B group), and 48 patients received traditional double-lumen endotracheal intubation (the DLET group). The study was approved by the independent medical ethical committee of the Peking Union medical College (IRB number S-1050) and all the patients signed extensive informed consents.

Anaesthetic and surgical procedure

General anaesthesia was adopted in all patients. In the DLET group, a 7-Fr or 7.5-Fr single-lumen endotracheal tube was inserted. Then, a bronchial blocker was inserted into the tube lumen under the guidance of a fibre bronchoscope to block the right main bronchus. The patient was arranged in a left semi-prone position inclined 45 degrees, and the tube and blocker position was confirmed again by auscultate. Artificial pneumothorax was created by CO_2 insufflation with a pressure of 8 mmHg. In the DLET group, a left double-lumen endobronchial intubation was inserted. The parameters of the anaesthetic machine and anaesthetic drugs were the same as those in the SLET-B group. A fibre bronchoscope was used to confirm the tube position in the left bronchus. After the patient was arranged in the same left semi-prone position as in the SLET-B group, the tube position was confirmed again by auscultate. If the endotracheal tube was displaced, it was adjusted and fixed again by fibre bronchoscopy.

In the thoracic phase, the oesophagus was mobilized, and standard lymphadenectomy was performed, especially bilateral recurrent laryngeal nerve lymph nodes and subcarinal nodes. Then, the patient was turned to the supine position. The bronchial blocker was removed in the DLET group, and both groups resumed two-lung ventilation. Laparoscopic abdominal exploration was performed, including stomach mobilization, lymphadenectomy and feeding jejunostomy. Otherwise, cervical anastomosis was performed through a left cervical incision. Selective cervical lymphadenectomy was performed according to the preoperative ultrasonography of suspicious metastatic cervical lymph nodes. All patients were transferred to the intensive care unit under anaesthesia after the operation, and the dual-lumen endotracheal tube was replaced with a single-lumen endotracheal tube in patients in the DLET group.

Variables collection

We collected the baseline characteristics, intraoperative haemodynamics during anaesthesia, surgical and postoperative characteristics in this study.

Statistical analysis

Analysis was performed using Statistical Product and Service Solutions 19.0 statistical software. The measurement data are expressed as $x \pm s$. The t-test was used to compare the means between groups. The chi-squared test was used to compare the count data. Differences for which P values were < 0.05 were considered significant.

Results

The baseline characteristics are presented in Table 1. A total of 117 patients were assigned to the SLET-B group, and 48 patients were assigned to the DLET group. No significant differences were observed between the two groups in age, sex, preoperative pulmonary function (forced expiratory volume in 1 second/forced vital capacity, FEV1/FVC), American Society of Anesthesiologists (ASA) grading, tumour location, pathology, neoadjuvant therapy, postoperative staging (TNM staging according to the 2015 Union for International Cancer Control guidelines) or concomitant disease.

Table 1
Baseline characteristics

Variables	SLET-B group (N = 117)	DLET group (N = 48)	P value
Age (years)	61.84 ± 8.17	61.42 ± 9.04	0.771
Sex			0.728
Male	100	40	
Female	17	8	
FEV 1/FVC (%)	81.09 ± 7.95	80.59 ± 9.54	0.728
ASA grading			0.134
I	11	10	
II	94	34	
III	12	4	
Tumour location			0.497
Upper	22	13	
Middle	63	23	
Lower	32	12	
Pathology			0.801
Squamous cell carcinoma	106	45	
Adenocarcinoma	7	2	
Other	4	1	
Neoadjuvant therapy			0.417
No	76	36	
Chemotherapy	39	11	
hemotherapy + radiotherapy	2	1	
Postoperative staging			0.788
I	33	17	
II	40	14	
III	37	15	
IVA	7	2	
Concomitant disease			
Hypertension	38	20	0.262
Diabetes mellitus	22	10	0.765

Variables	SLET-B group (N = 117)	DLET group (N = 48)	P value
Cardiovascular disease	19	12	0.191
Respiratory disease	26	15	0.223
Field of lymphadenectomy			0.317
Two-field	92	41	
Three-field	25	7	

The patient characteristics and intraoperative haemodynamics during anaesthesia are presented in Table 2. Characteristics including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), blood oxygen saturation (SpO_2), peak airway pressure (Ppeak), end-tidal carbon dioxide pressure ($PetCO_2$), and arterial blood gas value (potential of hydrogen, pH; partial pressure of oxygen, PaO_2; partial pressure of carbon dioxide, $PaCO_2$) were collected at four time points: T0 (before anaesthesia), T1 (45 minutes after the thoracic phase started), T2 (90 minutes after the thoracic phase started), and T3 (half an hour after the thoracic phase ended). Before anaesthesia (T0), there were no significant differences between the two groups. In the thoracic phase (T1 and T2), patients had lower HR, SBP, DBP, and pH and higher Ppeak, $PetCO_2$, PaO_2, and $PaCO_2$ after CO_2 insufflation. Furthermore, the SLET-B group had higher pH and lower Ppeak, $PetCO_2$, and $PaCO_2$ than the DLET group ($P < 0.05$). These parameters were alleviated after the thoracic phase (T3), and no differences were found between the two groups except arterial blood pH.

Table 2
Patient characteristics and intraoperative haemodynamics during anaesthesia. *P < 0.05 compared between two groups

T3	**DLET**	**69.15 ± 10.06**	**115.25 ± 13.07**	**64.04 ± 7.09**	**98.85 ± 1.66**	**22.02 ± 5.90**	**36.04 ± 4.73**	**7.33 ± 0.05**	**201.72 ± 60.78**	**44.83 ± 6.14**
	SLET-B	**70.58 ± 10.25**	**112.54 ± 12.14**	**64.96 ± 7.56**	**99.32 ± 1.51**	**20.70 ± 4.65**	**35.09 ± 4.14**	**7.35 ± 0.05***	**219.44 ± 62.38**	**42.92 ± 6.16**
T2	DLET	72.00 ± 10.16	116.71 ± 15.11	68.43 ± 8.29	99.38 ± 1.18	29.15 ± 6.91	46.67 ± 5.06	7.27 ± 0.06	188.27 ± 51.31	55.44 ± 7.34
	SLET-B	69.59 ± 8.59	112.98 ± 13.00	67.44 ± 7.86	99.49 ± 1.06	26.44 ± 5.11*	44.74 ± 5.24*	7.29 ± 0.05*	185.44 ± 47.16	53.04 ± 6.06*
T1	DLET	70.08 ± 9.01	113.79 ± 19.21	63.88 ± 10.83	99.17 ± 1.23	29.65 ± 7.07	44.38 ± 5.77	7.27 ± 0.05	169.73 ± 47.44	53.13 ± 9.78
	SLET-B	69.49 ± 8.76	113.87 ± 13.16	66.52 ± 9.02	99.46 ± 1.13	27.14 ± 4.98*	41.53 ± 5.40*	7.30 ± 0.07*	181.04 ± 48.45	48.62 ± 9.24*
T0	DLET	74.17 ± 10.80	120.50 ± 15.28	72.04 ± 11.85	99.33 ± 1.23	22.17 ± 5.98	36.25 ± 3.93	7.37 ± 0.05	91.17 ± 9.53	39.81 ± 4.40
	SLET-B	73.58 ± 12.63	121.96 ± 16.86	71.01 ± 10.54	99.58 ± 1.06	21.16 ± 5.18	37.46 ± 3.94	7.39 ± 0.05	92.03 ± 7.94	39.45 ± 4.11
Variables		HR (bpm)	SBP (mmHg)	DBP (mmHg)	SpO2 (%)	Ppeak (mmHg)	$PetCO_2$ (mmHg)	pH	PaO_2 (mmHg)	$PaCO_2$ (mmHg)

Surgical and postoperative characteristics are presented in Table 3. The SLET-B group had a significantly shorter intubation time and lower tube translocation rate than the DLET group. The tube translocation rates were similar between the two groups. The SLET-B group had less intraoperative haemorrhage, shorter thoracic phase time, shorter total hospital stay and more harvested bilateral recurrent laryngeal and total thoracic lymph nodes than the DLET group. However, no differences were found in total operation time, intraoperative blood transfusion, conversion to thoracotomy or postoperative complications between the two groups.

Table 3
Surgical and postoperative characteristics

Variables	SLET-B group	DLET group	P value
Intubation time (minutes)	18.28 ± 5.00	21.33 ± 4.63	< 0.001
Tube translocation	7	8	< 0.05
Total hospital stay (days)	15.05 ± 12.43	19.13 ± 8.60	< 0.05
Thoracic phase time (minutes)	111.45 ± 47.45	143.54 ± 61.25	< 0.001
Total operation time (minutes)	305.77 ± 54.87	323.54 ± 61.25	0.070
Intraoperative haemorrhage (ml)	185.13 ± 109.62	239.58 ± 99.98	< 0.01
Intraoperative blood transfusion	3	2	0.585
Conversion to thoracotomy	1	1	0.512
Lymph node harvest			
Left RLN	6.97 ± 5.05	2.58 ± 1.16	< 0.001
Right RLN	4.30 ± 3.21	2.52 ± 1.68	< 0.001
Total thoracic	24.89 ± 11.53	15.96 ± 5.53	< 0.001
Postoperative complications			
Anastomosis leak	10	6	0.436
RLN paralysis	12	8	0.252
Respiratory complications	6	5	0.216
Cardiovascular complications	5	2	0.975
Chylothorax	2	1	0.870
Postoperative mortality	1	0	0.521

Discussion

In recent years, minimally invasive oesophagectomy has become the recommended treatment for resectable oesophageal cancer. Double-lumen endotracheal intubation is the most commonly used anaesthetic method for thoracic surgery, and it can achieve single-lung ventilation to provide sufficient surgical field exposure. However, the shortcomings of this anaesthetic method include the complicated intubation process, high incidence of tube translocation during operation, difficulty in adjustment, and postoperative respiratory complications. Furthermore, it is difficult to access the aortopulmonary window and left recurrent laryngeal nerve due to the lower tracheal mobility of the double-lumen endotracheal tube. Complications such as aorta/pulmonary artery injury and recurrent laryngeal nerve paralysis may occur during lymphadenectomy (3). Single-lumen endotracheal intubation combined with bronchial occlusion has the following advantages (4). First, the application access is relatively simple. The bronchial blocker can provide an effective seal of the bronchus with minimal trauma to achieve single-lung ventilation. Furthermore, the intraoperative adjustment is simple, as the surgeon can help to adjust the position of the blocker under the direct vision of the operation. Second, single-lumen endotracheal intubation causes less damage to the airway mucosa and respiratory tract, while dual-lumen endotracheal intubation usually causes postoperative pharyngeal discomfort or pain. Third, after the thoracic phase of surgery, one only needs to remove the bronchial blocker for subsequent surgery. Patients need to be changed to a single endotracheal tube when returning to the intensive care unit after surgery, which can cause secondary injuries as well as postoperative pharyngeal discomfort. In our study, the advantages of perioperative tube management were shown by the significantly lower intubation time and intraoperative tube dislocation rate in the SLET-B group than in the DLET group.

When CO_2 is continuously insufflated into the thoracic cavity, the internal pressure of the pleural cavity changes from negative pressure to positive pressure, forming tension pneumothorax, leading to lung collapse, which achieves the purpose of surgical field exposure. Palanivelu et al used CO_2 pneumothorax for the first time in thoracoscopy for oesophageal cancer in 2006 and found that it could reduce postoperative respiratory complications (5). Artificial pneumothorax can provide satisfactory surgical field exposure of the mediastinal space and facilitate the dissection of lymph node tissues, reducing intraoperative haemorrhage and the probability of accidental injury during surgery. In our study, intraoperative haemorrhage, thoracic phase time and total hospital stay in the SLET-B group were less than those in the DLET group. At the same time, the number of bilateral recurrent RLNs and the total number of thoracic lymph nodes harvested were significantly higher than in the DLET group. Optimized lymphadenectomy can help us to acquire accurate postoperative pathological staging, which may improve the survival rate in oesophageal cancer patients. Furthermore, there were fewer postoperative complications in the SLET-B group, although no significance was found.

The safety of CO_2 pneumothorax is an aspect that needs attention. First, lung collapse, low tidal volume ventilation and direct absorption of carbon dioxide may lead to hypercapnia and acidosis during surgery, which may cause potential damage to the lungs, especially in patients with poor pulmonary function. Second, haemodynamic disturbances may lead to cardiac insufficiency in high-risk patients. Furthermore, CO_2 pneumothorax may cause gas embolization in rare cases. Garg et al considered that when oxygenation and circumfusion are sufficient, permissible hypercapnia (PHV) allows a maximum $PaCO_2$ of 67 mmHg and a minimum pH of 7.2 in arterial blood gas (6). According to previous research, carbon dioxide artificial pneumothorax under low pressure (< 8 mmHg) has no significant effect on respiration and circulation (7). In our study, after 8 mmHg CO_2 insufflation, arterial blood gas analysis and ventilator parameters indicated a decrease in pH and an increase in $PetCO_2$ and $PaCO_2$, suggesting acidosis and hypercapnia within acceptable levels. After the end of artificial pneumothorax, these abnormalities were relieved, which fit the protective lung ventilation strategy. In terms of respiratory circulation, heart rate, blood pressure, blood oxygen saturation and other indicators were not significantly different. Furthermore, better anaesthetic conditions were acquired in the SLET-B group with significantly higher pH and lower Ppeak, $PetCO_2$, and $PaCO_2$ than in the DLET group. Therefore, our study indicates that CO_2 artificial pneumothorax is safe under strict control of CO_2 pressure and standardized protocols.

The bronchial blocker also has limitations in the suction of airway secretions and difficulty in lung inflation, which makes its use restricted in lung surgery. With fewer airway secretions and the requirement of repeated lung collapse and inflation, the use of bronchial blockers has more advantages in oesophagectomy. Another disadvantage is the inability of continuous intraoperative suction, which may cause difficulty in the haemostatic process and increased operation time. In our study, however, the operation time and intraoperative haemorrhage in the thoracic phase were significantly shorter in the SLET-B group, which is consistent with the results of another study (8). Therefore, we believe that this shortcoming can be overcome through more experience with this surgical technique.

Still, several limitations in our study are noted. First, this is a retrospective study, and although baseline characteristics were comparable, patient selection bias may exist. In addition, our data included patients who underwent MIE from 2014 to 2019, but the SLET-B method has only been applied since 2017. Thus, more experience with this surgical technique may contribute to a better outcome in the SLET-B group.

Conclusions

Therefore, single-lumen endotracheal intubation combined with right bronchial occlusion under artificial pneumothorax is feasible and safe in MIE under strict control of CO_2 pressure and standardized protocols. It had advantages in tube management, surgical field exposure, shortened surgery time, increased efficiency of lymphadenectomy and fewer postoperative complications.

List Of Abbreviations

MIE
minimally invasive oesophagectomy; CO_2:carbon dioxide; RLN:recurrent laryngeal nerve; PET:positron emission tomography; MRI:nuclear magnetic resonance; SLET-B:single-lumen endotracheal intubation combined with right bronchial occlusion; DLET:double-lumen endotracheal intubation; FEV1/FVC:forced expiratory volume in 1 second/forced vital capacity; ASA:American Society of Anesthesiologists; HR:heart rate; SBP:systolic blood pressure; DBP:diastolic blood pressure; SpO_2:blood oxygen saturation:Ppeak:peak airway pressure; $PetCO_2$:end-tidal carbon dioxide pressure; pH:potential of hydrogen; PaO_2:partial pressure of oxygen; $PaCO_2$:partial pressure of carbon dioxide; PHV:permissible hypercapnia

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the independent medical ethical committee of the Peking Union medical College (IRB number S-1050) and all the patients signed extensive informed consents.

Availability of data and materials

The datasets supporting the conclusions of this article are included within the article and its additional files.

Competing interests

Not applicable.

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Not applicable.

Authors' contributions

LL, LZ, JH, ZJH performed the conception and design. LL, LZ analyzed and interpreted the patient data. LL, LZ, JH, ZJH drafted the manuscript and all authors read and approved the final manuscript. Li Li & Luo Zhao contribute equally to the manuscript.

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