Original Article

A comparison between two lung ventilation with CO_2 artificial pneumothorax and one lung ventilation during thoracic phase of minimally invasive esophagectomy

Miao Lin*, Yaxing Shen*, Hao Wang, Yong Fang, Cheng Qian, Songtao Xu, Di Ge, Mingxiang Feng, Lijie Tan, Qun Wang

Department of Thoracic Surgery, Zhongshan Hospital, Fudan University, Shanghai 200032, China

Contributions: (I) Conception and design: M Lin, Y Shen, M Feng, L Tan; (II) Administrative support: Q Wang, M Feng, L Tan; (III) Provision of study materials or patients: C Qian, S Xu, D Ge, M Feng, L Tan, Q Wang; (IV) Collection and assembly of data: M Lin, Y Shen, H Wang, Y Fang; (V) Data analysis and interpretation: M Lin, Y Shen; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

*These authors contributed equally to this work.

Correspondence to: Mingxiang Feng and Lijie Tan, MD, PhD. Department of Thoracic Surgery, Zhongshan Hospital, Fudan University, Shanghai 200032, China. Email: Feng.mingxiang@zs-hospital.sh.cn; Tan.lijie@zs-hospital.sh.cn.

Background: To investigate the feasibility and safety of two lung ventilation with artificial pneumothorax in minimally invasive esophagectomy (MIE) through a comparison with conventional one lung ventilation.

Methods: Eleven hundred and sixty-six patients with esophageal cancer, who underwent McKeown MIE in our center from February 2006 to December 2016, were studied retrospectively. Seven hundred and five patients who underwent one lung ventilation with double lumen endotracheal tube (DLET) were assigned to DLET group. Other 461 patients who underwent two lung ventilation with single lumen endotracheal tube (SLET) were assigned to SLET group. Clinical characteristics, surgical variables and complications were compared between two groups.

Results: There were comparable patient characteristics in two groups. Surgical variables and complications were discussed between two groups. SLET group seemed to have shorter operative time, shorter postoperative hospital stay, and more harvested recurrent laryngeal nerve (RLN) lymph nodes than DLET group, which might be attributed to experienced surgeons. However, there were no significant differences of complications between two groups. Intraoperative clinical parameters were further studied. Before intubation and artificial pneumothorax, there were no significant differences between two groups, except diastolic blood pressure (DBP). With the application of artificial pneumothorax, patients in SLET group have obviously higher PO_2, PCO_2, and $PetCO_2$ value, and slightly lower pH value and blood pressure during thoracic phase. After the thoracic phase, the changes induced by artificial pneumothorax in SLET group were gradually reversed and clinical parameters gradually return to normal level.

Conclusions: Two lung ventilation with artificial pneumothorax is a safe and feasible choice during MIE.

Keywords: Two lung ventilation; single lumen endotracheal tube (SLET); minimally invasive esophagectomy (MIE); esophageal cancer; artificial pneumothorax

Submitted Dec 21, 2017. Accepted for publication Jan 26, 2018.
doi: 10.21037/jtd.2018.01.150
View this article at: http://dx.doi.org/10.21037/jtd.2018.01.150

Introduction

Esophageal cancer is one of the most common cancers in china, whose incidence rate and mortality rate were as high as 4.8‰ and 3.8‰ in 2015 (1). Surgical resection is considered to be the most effective treatment for early stage esophageal cancer. Researches indicated that open esophagectomy is related to significantly higher morbidity of perioperative complications, while minimally invasive esophagectomy (MIE) is proved to have better short term outcome and has gradually become a standard surgical approach for esophageal cancer in recent years (2,3).

Double lumen endotracheal tube (DLET) is commonly adopted for the anesthesia of MIE, which allows one lung ventilation in order to provide enough surgical space and good exposure. However, disadvantages of DLET anesthesia include rigorous requirement of pulmonary function, sophisticated procedure of intubation, high incidence of displacement during surgery, and frequent respiratory complications after surgery (4,5). Some patients with esophageal cancer are smokers and suffer from chronic respiratory diseases. These patients with poor pulmonary function have higher incidence of perioperative respiratory complications. Some even cannot bear one lung ventilation. Single lumen endotracheal tube (SLET) with CO_2 insufflation artificial pneumothorax, which is an alternative for DLET, allows two lung ventilation during surgery, and provides good exposure as well. However, Reports of SLET anesthesia in MIE are rare. Only Zhang *et al.* and Cai *et al.* reported 42 and 83 cases (6,7). In video-assisted thoracoscopic surgery (VATS), most application of two lung ventilation with SLET are found in endoscopic sympathectomy and spontaneous pneumothorax which do not require sophisticated surgical operation (4,8-13). As one of the largest esophageal center in china, we adopted SLET with CO_2 insufflation artificial pneumothorax and two lung ventilation in MIE since 2013. Here, we retrospectively studied patients who underwent MIE surgery in our center from February 2006 to December 2016, and assessed the safety and feasibility of application of SLET with CO_2 insufflation artificial pneumothorax in MIE.

Methods

Patients

Eleven hundred and sixty-six patients with esophageal cancer, who accepted minimally invasive McKeown three-phase esophagectomy in our center from February 2006 to December 2016 (*Figure S1*), were retrospectively studied. Seven hundred and five patients of them, who accepted general anesthesia with one lung ventilation using a DLET during the thoracic phase of surgery, were assigned to DLET group. Other 461 patients accepted anesthesia with two lung ventilation using a SLET and CO_2 insufflation (CO_2 pressure =8 mmHg) artificial pneumothorax and were assigned to SLET group. This study has been approved by the Ethics Committee of Zhongshan Hospital (No. B2017-153), and all patients signed informed consent.

Anesthetic and surgical procedure

Combined general-epidural anesthesia is adopted. All the patients adopted the minimally invasive McKeown three-phase esophagectomy (14), which includes the extracorporeal gastric conduit creation and cervical anastomosis between gastric conduit and esophagus. Patients were placed in the left lateral prone position during the thoracic phase and in the supine position during other two phases. The changes of heart rate (HR), blood pressure, SpO_2, $PetCO_2$ were collected from the anesthesia note. During surgery, artery blood sample was taken for blood gas analysis once in the thoracic phase (generally 30–60 minutes after the initiation of thoracic phase) and again after thoracic phase (generally 30–60 minutes after thoracic phase) by anesthetist. These data were also collected from the anesthesia note.

Statistical analysis

Data are presented as the mean ± SD. All statistical analysis was performed using SPSS 13.0, with $P<0.05$ considered statistically significant.

Results

Clinical characteristics of two groups were summarized in *Table 1*. There were no significant differences in clinical characteristics between two groups, including age, gender, American Society of Anesthesiologists (ASA) grading, smoker number, TNM staging, tumor location, pulmonary function, and concomitant disease.

Surgical variables and postoperative complications were compared between two groups (*Table 2*). SLET group seemed to have shorter total operative time, shorter thoracic phase time, shorter postoperative hospital stay, more harvested left recurrent laryngeal nerve (RLN) lymph

Table1 Characteristics of patients

Variables	SLET group (n=461)	DLET group (n=705)	P value
Age (years)	61.40±7.92	61.80±7.89	0.40
Gender			0.25
Male	359	527	
Female	102	178	
ASA			0.79
I	279	440	
II	147	216	
III	35	49	
IV	0	0	
Smokers	267	437	0.18
TNM stage			0.17
I	161	219	
II	193	334	
III	107	152	
Tumor location			0.97
Upper 1/3 thoracic oesophagus	53	84	
Middle 1/3 thoracic oesophagus	251	385	
Lower 1/3 thoracic oesophagus	157	236	
PFT's			
FEV1 (Act/Pred %)	84.47±17.76	84.64±18.40	0.88
DLCO (%)	81.28±16.80	80.50±17.43	0.45
Concomitant disease			
Cardiovascular disease	27	39	0.92
Respiratory disease	34	53	0.98
Diabetes	16	27	0.87

SLET, single lumen endotracheal tube; DLET, double lumen endotracheal tube; ASA, American Society of Anesthesiologists; DLCO, diffusing capacity of the lung for carbon monoxide; PFT, pulmonary function test.

nodes, and more total RLN lymph nodes than DLET group, which might be attributed to experienced surgeons in 2013–2016. However, there were no significant differences of complications between two groups. SLET group seemed to have the symptom of intraoperative hypotension during thoracic phase in a few patients, which could be relieved immediately by the removal of CO_2 insufflation.

Clinical parameters, including HR, systolic blood pressure (SBP), diastolic blood pressure (DBP), SpO_2, $PetCO_2$, and results of blood gas analysis (pH, PO_2, PCO_2) were investigated in three time points of surgery (before anesthesia, during thoracic phase, and after thoracic phase). Before anesthesia, there were no differences of these parameters between two groups, except the DBP. During thoracic phase, patients in SLET group had lower blood pressure, and pH value, but higher SpO_2, PO_2, PCO_2, and $PetCO_2$ than patients in DLET group. After thoracic phase, most of these changes were alleviated. Most variables showed no significant differences between two groups. Significant differences were only observed in SpO_2 and pH value.

Table2 Comparison of surgical variables and postoperative complications

Variables	SLET group (n=461)	DLET group (n=705)	P value
Total operative time (min)	191.12±29.02	214.01±35.23	<0.01
Thoracic phase time (min)	67.08±22.34	74.32±27.50	<0.01
Left RLN nodes (n)	3.92±1.99	2.40±1.76	<0.01
Total RLN nodes (n)	6.94±2.11	4.19±2.30	<0.01
Postoperative hospital stay (days)	10.21±9.03	11.41±9.41	0.03
Complications			
Anastomosis leak	53	81	0.93
Respiratory complications	26	43	0.84
Chylothorax	4	6	0.77
Hoarseness	24	36	0.95
Arrhythmia	19	28	0.98
Haemorrhage	3	6	0.97
Postoperative mortality	2	3	0.66
Intraoperative hypotension	3	0	0.12

SLET, single lumen endotracheal tube; DLET, double lumen endotracheal tube; RLN, recurrent laryngeal nerve.

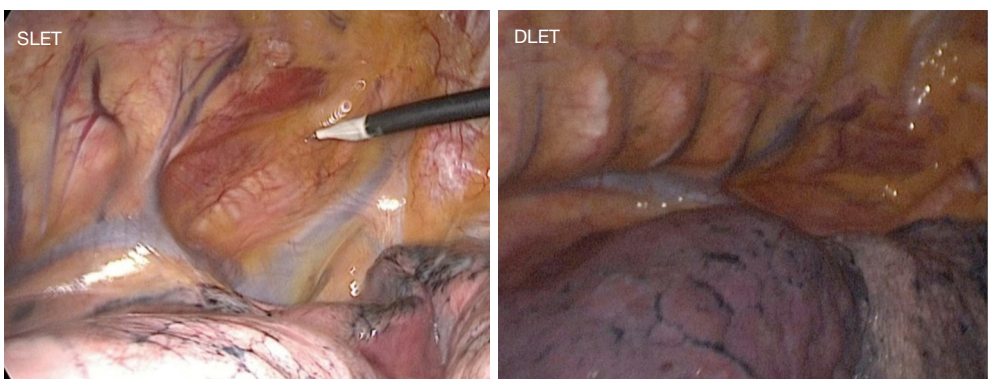


Figure 1 Good exposure with two lung ventilation. With the press on lung by the assistant, two lung ventilation with SLET could have good surgical exposure as one lung ventilation with DLET. SLET, single lumen endotracheal tube; DLET, double lumen endotracheal tube.

Discussion

Originally, one lung ventilation with DLET was the only choice during the anesthesia of patients who accepted MIE for the purpose of good exposure. However, researches have indicated some disadvantages of one lung ventilation with DLET (15-17), including airway injuries, intraoperative hypoxaemia, tracheobronchial injury, and so on. Many institutions have attempted to replace DLET with SLET in MIE nowadays, in order to avoid these defects. However, it's still controversial whether patients benefit from SLET with artificial pneumothorax. Most studies were too small to provide meaningful statistical results.

One defect of one lung ventilation with DLET is complicated preoperative intubation and perioperative management. During the placement of DLET, the assistant of a fiber-optic bronchoscope is necessary. Besides, intra-operative translocation of DLET is frequent observed, and replacement is then required which might interrupt surgery. If a patient suffers from tracheostenosis or tracheal

Table3 Changes of clinical parameters during surgery

Variables	Before anesthesia			During thoracic phase			After thoracic phase		
	SLET group (n=461)	DLET group (n=705)	P value	SLET group (n=461)	DLET group (n=705)	P value	SLET group (n=461)	DLET group (n=705)	P value
HR (bpm)	77.19±11.20	78.24±12.71	0.15	65.21±6.74	65.03±7.26	0.67	61.48±6.82	60.79±6.50	0.08
SBP (mmHg)	118.09±19.37	116.25±18.21	0.10	100.21±12.18	104.04±9.40	<0.01	102.66±13.66	101.87±13.58	0.33
DBP (mmHg)	81.38±15.54	83.79±18.95	0.02	61.97±13.38	65.98±10.75	<0.01	64.62±14.34	63.91±14.98	0.42
SpO_2 (%)	98.76±0.94	98.82±0.90	0.27	99.71±0.73	98.93±1.16	<0.01	99.81±0.79	99.63±0.85	<0.01
pH	7.40±0.04	7.40±0.04	>0.99	7.30±0.03	7.39±0.05	<0.01	7.38±0.03	7.39±0.05	<0.01
PO_2 (mmHg)	87.20±8.54	86.77±8.13	0.39	216.89±45.21	170.57±23.16	<0.01	231.67±46.25	230.44±47.80	0.66
PCO_2 (mmHg)	39.92±3.23	40.15±3.24	0.24	51.17±6.50	40.26±3.13	<0.01	40.20±3.11	39.99±3.19	0.27
$PetCO_2$ (mmHg)	–	–	–	46.07±4.89	35.22±3.17	<0.01	35.00 ±3.22	35.12±3.15	0.53

SLET, single lumen endotracheal tube; DLET, double lumen endotracheal tube; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure.

malformation, application of DLET seems very hard, and sometimes even impossible. The application of SLET, with easy access and management, does not have these defects. SLET with artificial pneumothorax has been adopted for more than 400 cases of MIE in our center. And its exposure of surgical area is as good as DLET (*Figure 1*).

Another defect of one lung ventilation with DLET is the requirement of good pulmonary function (18). Patients with poor pulmonary function might not tolerate one lung ventilation during surgery. Arterial oxygen tension decrease was sometimes observed during surgery with one lung ventilation. Although hypoxic pulmonary vasoconstriction of the nonventilated lung might decrease the hypoxia effect, it's still not as good as two lung ventilation and occasionally develops to severe hypoxemia. This complication is commonly observed in elderly patients with poor pulmonary function (19). Some respiratory complications of MIE are related to one lung ventilation and intraoperative hypoxemia. A few patients would even develop postoperative pulmonary atelectasis and infection after one lung ventilation with DLET. We compared the intraoperative PO_2 level between patients in SLET group and DLET group, and found the incidence of hypoxemia was greatly decreased in SLET group. In the 461 patients in SLET group, none was observed with intraoperative hypoxemia. Statistical analysis also proved significantly higher PO_2 level during thoracic phase in SLET group (*Table 2*).

Safety is the main concern of surgical anesthesia. Artificial pneumothorax with CO_2 insufflation helps exposure the surgical area needed, but also might cause severe complications as reported (7,12), including cardiovascular collapse, ventricular arrhythmias, and contralateral pneumothorax. However, reported cases of severe complications are rare and most of these studies have some limitations, like small amount of enrolled patient, inappropriate pressure of insufflated CO_2, unstandardized protocols, and so on. Further evaluation is necessary. In our study, we retrospectively studied 461 patients underwent artificial pneumothorax with CO_2 as SLET group retrospectively. Eight mmHg of CO_2 insufflation pressure was adopted during thoracic phase of MIE. No severe respiratory and circulatory complications were observed. We compared the circulatory and respiratory data between SLET group and DLET group. In SLET group, slight change of blood pressure and HR could be found, which was induced by 8 mmHg pressure of CO_2 insufflation. Three cases of intraoperative hypotension were observed, but immediately reversed by removal of CO_2 insufflation.

The pH value was greatly decreased, while PO_2, PCO_2, and $PetCO_2$ were greatly increased after CO_2 insufflation (*Table 3*). CO_2 absorption could induce respiratory acidosis and increase the PCO_2 and $PetCO_2$. But these changes did not last long and returned to normal level after removal of CO_2 insufflation. Thus, our research indicates that artificial pneumothorax with CO_2 insufflation is safe under limited pressure of insufflated CO_2 and standardized protocol.

Another possible defect of SLET is the requirement of consistent CO_2 insufflation and stable pressure. When the surgeon decided to change to open surgery or Ivor Lewis esophagectomy during McKeown MIE, it would be hard to maintain good surgical exposure without CO_2 pressure. Under this condition, SLET needs to be changed to DLET during surgery.

In order to evaluate the clinical feasibility of two lung ventilation in MIE, we compared the surgical variables and complications between SLET group and DLET group. With similar background of patient characteristics, SLET group seemed to have shorter total operative time, shorter thoracic phase time, shorter postoperative hospital stay, more harvested left RLN lymph nodes, and more total RLN lymph nodes than DLET group. Our data included MIE cases from 2006 to 2016, but SLET was only applied since 2013. Thus, the better outcome of surgical variables of SLET group might be related to more experienced thoracic surgeon in recent years.

In conclusion, our data presented that two lung ventilation with artificial pneumothorax is a safe and feasible choice for MIE. It has the advantages of simple management, good exposure, few complications, and so on. Circulatory inhibition might be a focus of SLET disadvantages, while our study showed no case of severe circulatory complications under limited CO_2 pressure and standardized protocol.

Acknowledgements

Funding: This study was supported by the National Nature Science Foundation of China (grant numbers: 81370587, 81500568, 81400681).

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: This study has been approved by the Ethics Committee of Zhongshan Hospital (No. B2017-153), and all patients signed informed consent.

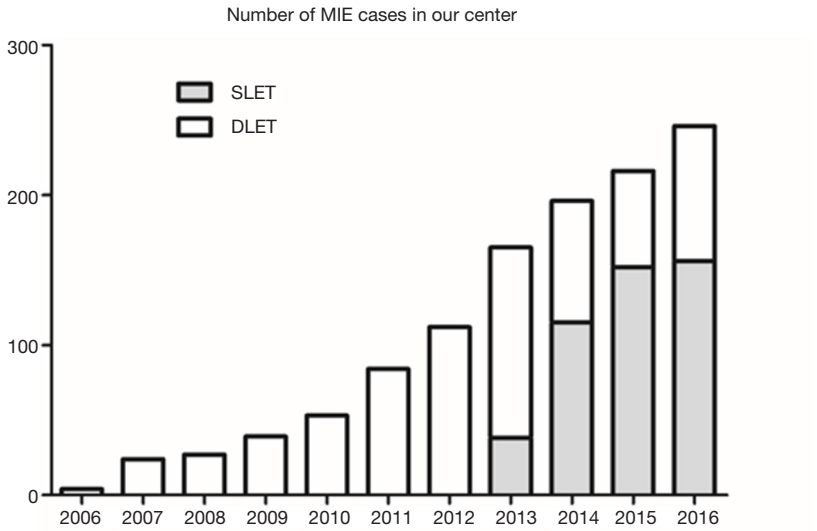
References

1. Chen W, Zheng R, Baade PD, et al. Cancer statistics in China, 2015. CA Cancer J Clin 2016;66:115-32.
2. Straatman J, van der Wielen N, Cuesta MA, et al. Minimally Invasive Versus Open Esophageal Resection: Three-year Follow-up of the Previously Reported Randomized Controlled Trial: the TIME Trial. Ann Surg 2017;266:232-6.
3. Takeuchi H, Miyata H, Ozawa S, et al. Comparison of Short-Term Outcomes Between Open and Minimally Invasive Esophagectomy for Esophageal Cancer Using a Nationwide Database in Japan. Ann Surg Oncol 2017;24:1821-7.
4. Cerfolio RJ, Bryant AS, Sheils TM, et al. Video-assisted thoracoscopic surgery using single-lumen endotracheal tube anesthesia. Chest 2004;126:281-5.
5. Cantwell SL, Duke T, Walsh PJ, et al. One-lung versus two-lung ventilation in the closed-chest anesthetized dog: a comparison of cardiopulmonary parameters. Vet Surg 2000;29:365-73.
6. Cai L, Li Y, Sun L, et al. Better perioperative outcomes in thoracoscopic-esophagectomy with two-lung ventilation in semi-prone position. J Thorac Dis 2017;9:117-22.
7. Zhang R, Liu S, Sun H, et al. The application of single-lumen endotracheal tube anaesthesia with artificial pneumothorax in thoracolaparoscopic oesophagectomy. Interact Cardiovasc Thorac Surg 2014;19:308-10.
8. Wong RY, Fung ST, Jawan B, et al. Use of a single lumen endotracheal tube and continuous CO2 insufflation in transthoracic endoscopic sympathectomy. Acta Anaesthesiol Sin 1995;33:21-6.
9. Cheng YL, Huang TW, Lee SC, et al. Video-assisted thoracoscopic surgery using single-lumen endotracheal tube anaesthesia in primary spontaneous pneumothorax. Respirology 2010;15:855-9.
10. Misthos P, Katsaragakis S, Milingos N, et al. Postresectional pulmonary oxidative stress in lung cancer patients. The role of one-lung ventilation. Eur J Cardiothorac Surg 2005;27:379-82; discussion 382-3.
11. Knoll H, Ziegeler S, Schreiber JU, et al. Airway injuries after one-lung ventilation: a comparison between double-lumen tube and endobronchial blocker: a randomized, prospective, controlled trial. Anesthesiology 2006;105:471-7.

12. Harris RJ, Benveniste G, Pfitzner J. Cardiovascular collapse caused by carbon dioxide insufflation during one-lung anaesthesia for thoracoscopic dorsal sympathectomy. Anaesth Intensive Care 2002;30:86-9.
13. Wolfer RS, Krasna MJ, Hasnain JU, et al. Hemodynamic effects of carbon dioxide insufflation during thoracoscopy. Ann Thorac Surg 1994;58:404-7; discussion 407-8.
14. Lin M, Shen Y, Feng M, et al. Minimally invasive esophagectomy: Chinese experiences. J Vis Surg 2016;2:134.
15. Frölich MA, Janelle GM. Postoperative atelectasis after one-lung ventilation with the Univent tube in a child. J Clin Anesth 2003;15:159-63.
16. Roth JV. Complications of One-lung Ventilation: Is It the Blood Flow or the Ventilation? Anesthesiology 2016;125:1253-4.
17. Durkin C, Schisler T, Lohser J. Current trends in anesthesia for esophagectomy. Curr Opin Anaesthesiol 2017;30:30-5.
18. Benumof JL. One-lung ventilation and hypoxic pulmonary vasoconstriction: implications for anesthetic management. Anesth Analg 1985;64:821-33.
19. Lin F, Pan L, Huang B, et al. Pressure-controlled versus volume-controlled ventilation during one-lung ventilation in elderly patients with poor pulmonary function. Ann Thorac Med 2014;9:203-8.

Cite this article as: Lin M, Shen Y, Wang H, Fang Y, Qian C, Xu S, Ge D, Feng M, Tan L, Wang Q. A comparison between two lung ventilation with CO_2 artificial pneumothorax and one lung ventilation during thoracic phase of minimally invasive esophagectomy. J Thorac Dis 2018;10(3):1912-1918. doi: 10.21037/jtd.2018.01.150

Supplementary



Yera	Number of total MIE cases	Number of total SLET cases	Number of total DLET cases
2006	4	0	4
2007	24	0	24
2008	27	0	27
2009	39	0	39
2010	53	0	53
2011	84	0	84
2012	112	0	112
2013	165	38	127
2014	196	115	81
2015	216	152	64
2016	246	156	90
SUM	1166	461	705

Figure S1 Number of MIE cases in our center from 2006–2016. MIE, minimally invasive esophagectomy; SLET, single lumen endotracheal tube; DLET, double lumen endotracheal tube.